Aerospace Systems Engineering
The Fuzzy Front End

Dr. Daniel P. Schrage
Professor and Director, CASA, CERT, & PLMC
Dr. Dan DeLaurentis
Asst. Professor, ASDL
School of Aerospace Engineering
Georgia Institute of Technology
Atlanta, GA 30332-0150

Presentation Outline

- Introduction to Systems Engineering, the Systems Engineering Process and Systems Analysis
- Modern Systems Engineering and the Quality Revolution
- The Five Lean Principles as Guiding Principles for Modern Systems Engineering
- Integrated Product/Process Development (IPPD) through Robust Design Simulation (RDS) for the Fuzzy Front End to Identify Customer Value and the Value Stream
- The Goal for Perfection through creation of a Virtual Stochastic Life Cycle Design Environment (VSLCDE)
- A Robust Design Simulation (RDS) Example

Systems Engineering

- **Systems Engineering** has been defined as an *interdisciplinary engineering management process* to evolve and verify an *integrated, life cycle balanced set* of *system solutions* that *satisfy customer needs* (SE Fundamentals, DSMC, 1999)
- **Systems Engineering methods and tools** were developed in the early 1960s to *decompose and breakdown* complex Aerospace Systems, e.g. Ballistic Missile, Launch Vehicles, Aircraft
- These methods and tools contributed greatly to winning the "**Space Race**" and the "**Cold War**"
- However, a *Modern Approach to Systems Engineering* must reflect the **Quality Revolution** which has driven industry for the past 20 years

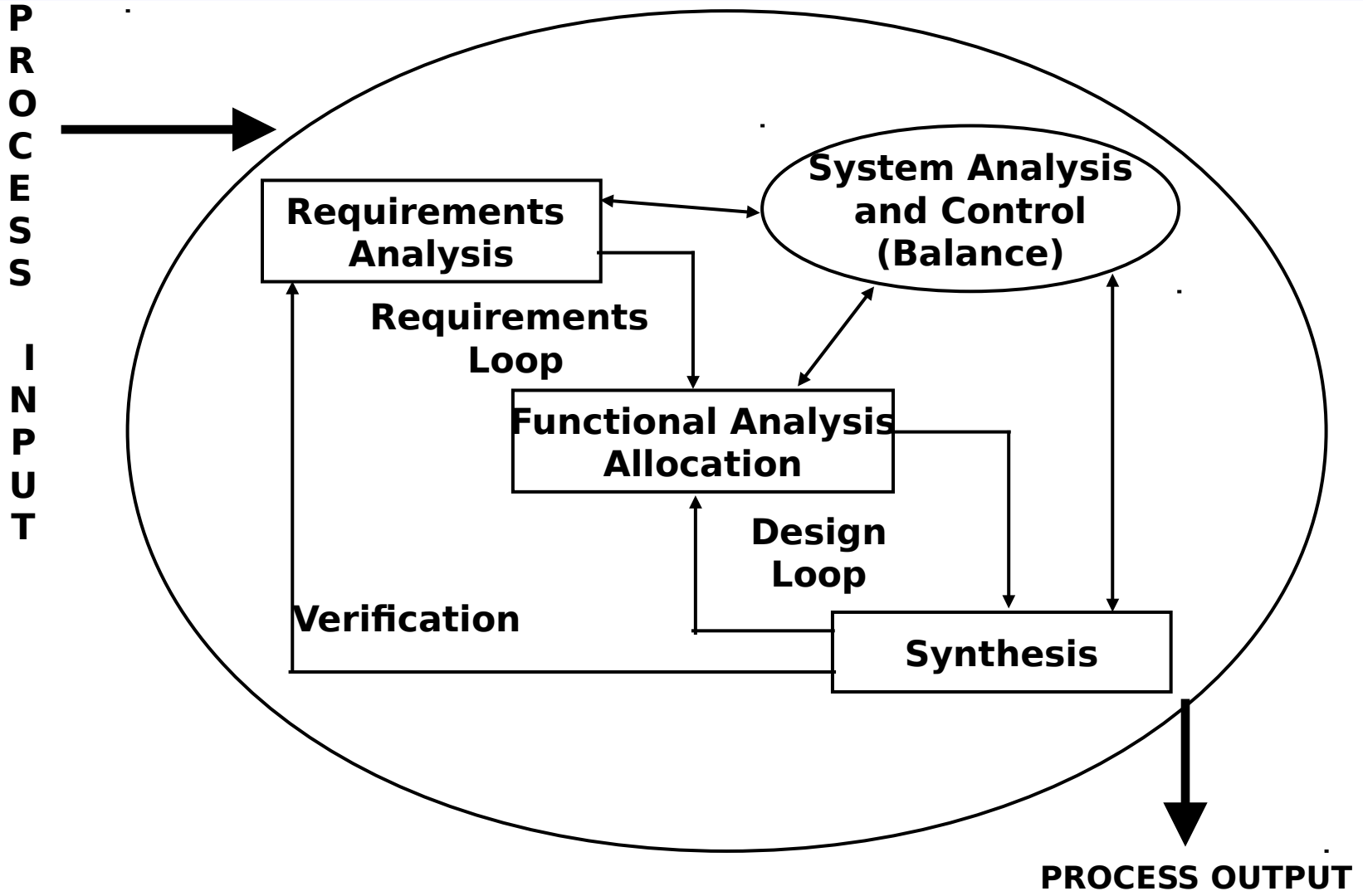
Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

The Systems Engineering Process

- As developed for the Department of Defense (DoD) the **Systems Engineering Process** includes three major elements:
  - *Requirements Analysis*
  - *Functional Analysis and Allocation*
  - *Synthesis*
- **Systems Analysis and Control** include the techniques and tools to analyze and control the Systems Engineering Process
- The **Systems Engineering Process** is applied to each stage of life cycle development, one level at a time

Process

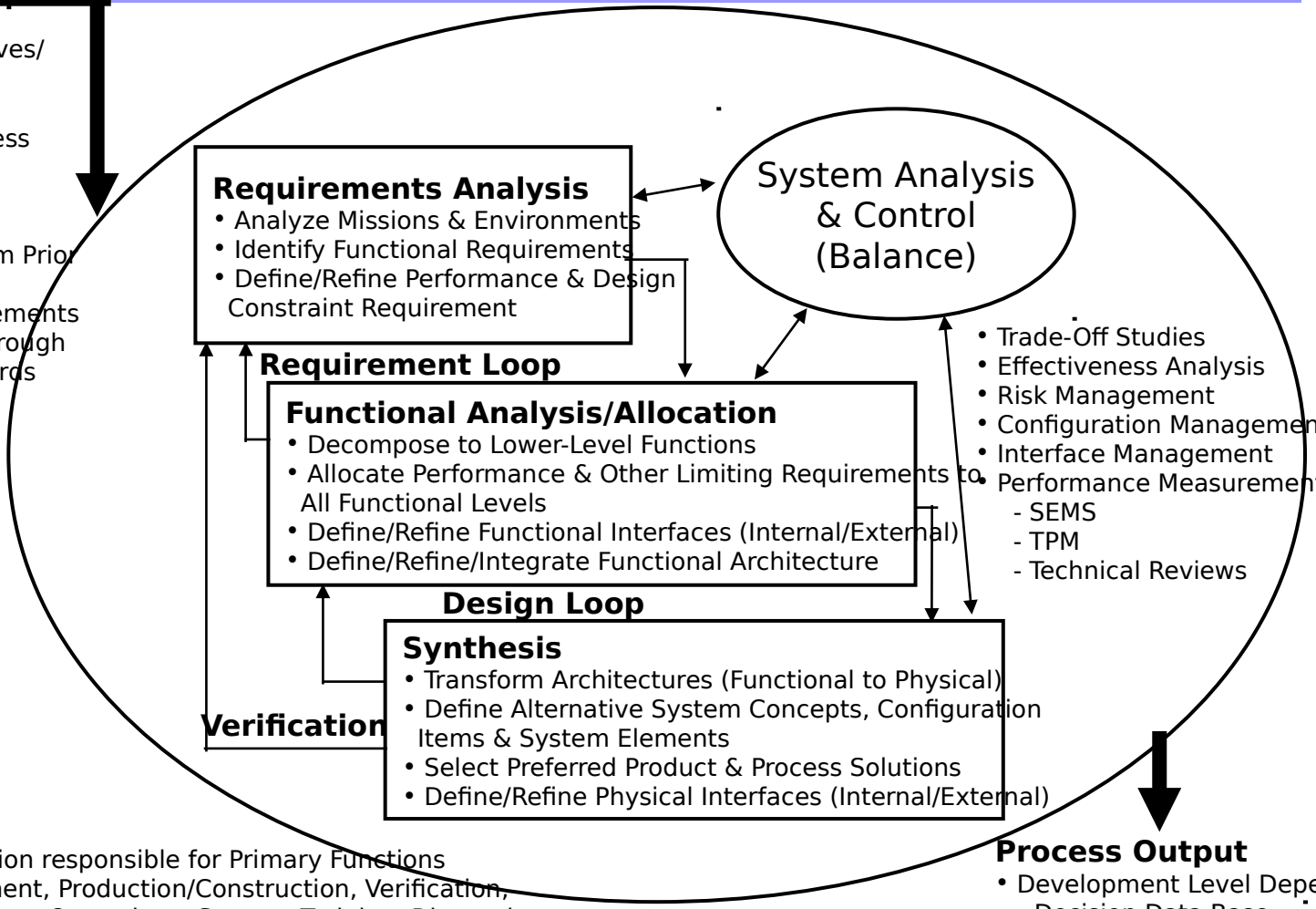
(SE Fundamentals, DSMC, 1999)



The Systems Engineering Process

Process Input

- Customer Needs/Objectives/ Requirements
  - Missions
  - Measures of Effectiveness
  - Environments
  - Constraints
- Technology Base
- Output Requirements from Prior Development Effort
- Program Decision Requirements
- Requirements Applied Through Specifications and Standards


Requirements Analysis
• Analyze Missions & Environments
• Identify Functional Requirements
• Define/Refine Performance & Design Constraint Requirement
System Analysis & Control (Balance)
Requirement Loop
Functional Analysis/Allocation
• Decompose to Lower-Level Functions
• Allocate Performance & Other Limiting Requirements to All Functional Levels
• Define/Refine Functional Interfaces (Internal/External)
• Define/Refine/Integrate Functional Architecture
Design Loop
Synthesis
• Transform Architectures (Functional to Physical)
• Define Alternative System Concepts, Configuration Items & System Elements
• Select Preferred Product & Process Solutions
• Define/Refine Physical Interfaces (Internal/External)
Verification
• Trade-Off Studies
• Effectiveness Analysis
• Risk Management
• Configuration Management
• Interface Management
• Performance Measurement
- SEMS
- TPM
- Technical Reviews

Related Terms:

Customer = Organization responsible for Primary Functions
Primary Functions = Development, Production/Construction, Verification, Deployment, Operations, Support Training, Disposal
Systems Elements = Hardware, Software, Personnel, Facilities, Data, Material, Services, Techniques

Process Output

- Development Level Dependa
  - Decision Data Base
  - System/Configuration Item Architecture
  - Specification & Baseline

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Why Systems Analysis?

- ***Systems Analysis* is a *scientific process***, or methodology, which can best be described in terms of its salient problem-related elements. The process involves:
  - ***Systematic examination and comparison of those alternative actions*** which are related to the accomplishment of desired objectives
  - ***Comparison of alternatives on the basis of the costs and the benefits*** associated with each alternative
  - ***Explicit consideration of risk***
- NASA, DoD, and Industry are realizing that more emphasis must be placing on **enhancing systems analysis at the front end** of the life cycle using modern systems engineering approaches

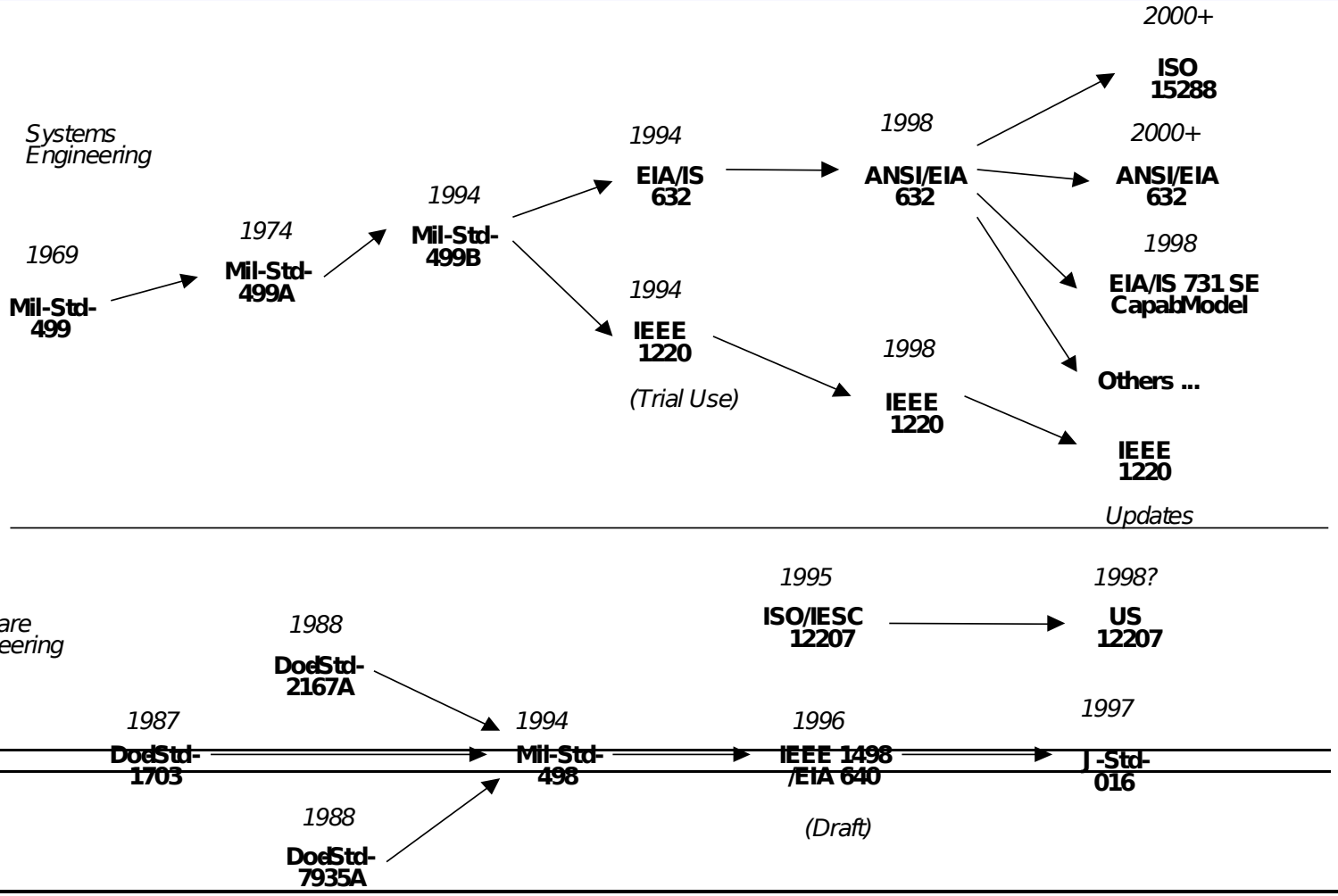
Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Lean Principles for Modern Systems Engineering

- ***Systems Engineering*** developed in the early 1960s for a ***top down hardware decomposition approach***
- ***Systems Analysis and Control*** used to track and evaluate implementation
- ***Work Breakdown Structure (WBS)*** identified work packages for pulling in the complete supply chain
- ***Software Engineering*** was developed in 1980s along a parallel path
- ***Quality Revolution of the 1980's*** revealed the need for a quality emphasis, e.g. Concurrent Engineering, IPPD, JIT Six Sigma and Lean Manufacturing
- Quality Emphasis has cumulated into a set of ***Lean Principles*** , as first identified in the Womack and Jones Book on ***Lean Thinking***
- ***Modern Systems Engineering*** should start with the Lean Principles as Guiding Principles

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

and Software Engineering Standards



Application of standards is the realm of Systems Engineers

Source: INCOSE Systems Engineering Handbook

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
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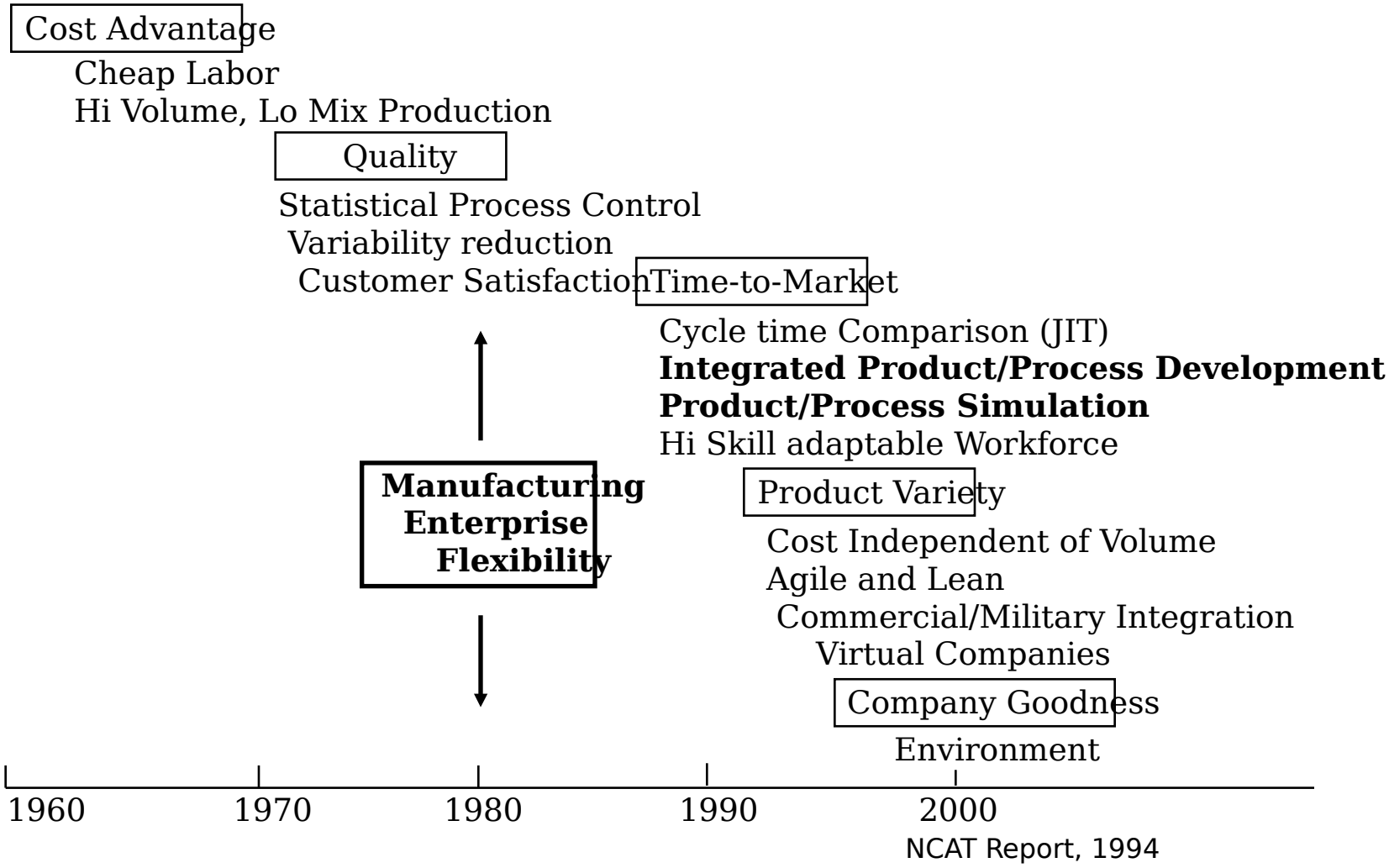
Quality Revolution - Where Competition is Today



NCAT Report, 1994

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Georgia Institute of Technology
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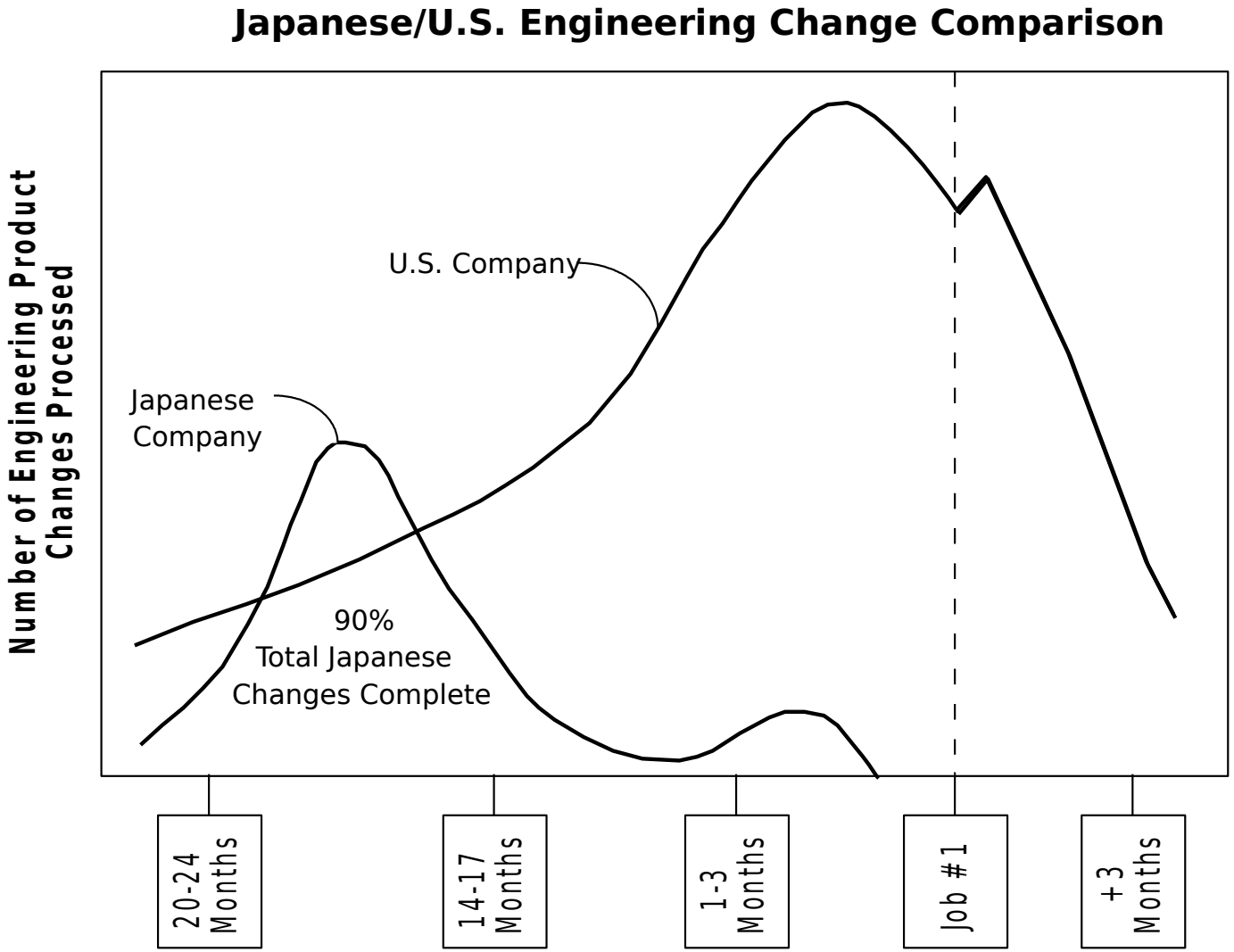
Engineering To Make Design Changes Earlier Than U.S. Auto Industry with Reduced Cycle Time



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Georgia Institute of Technology
Atlanta, GA 30332-0150
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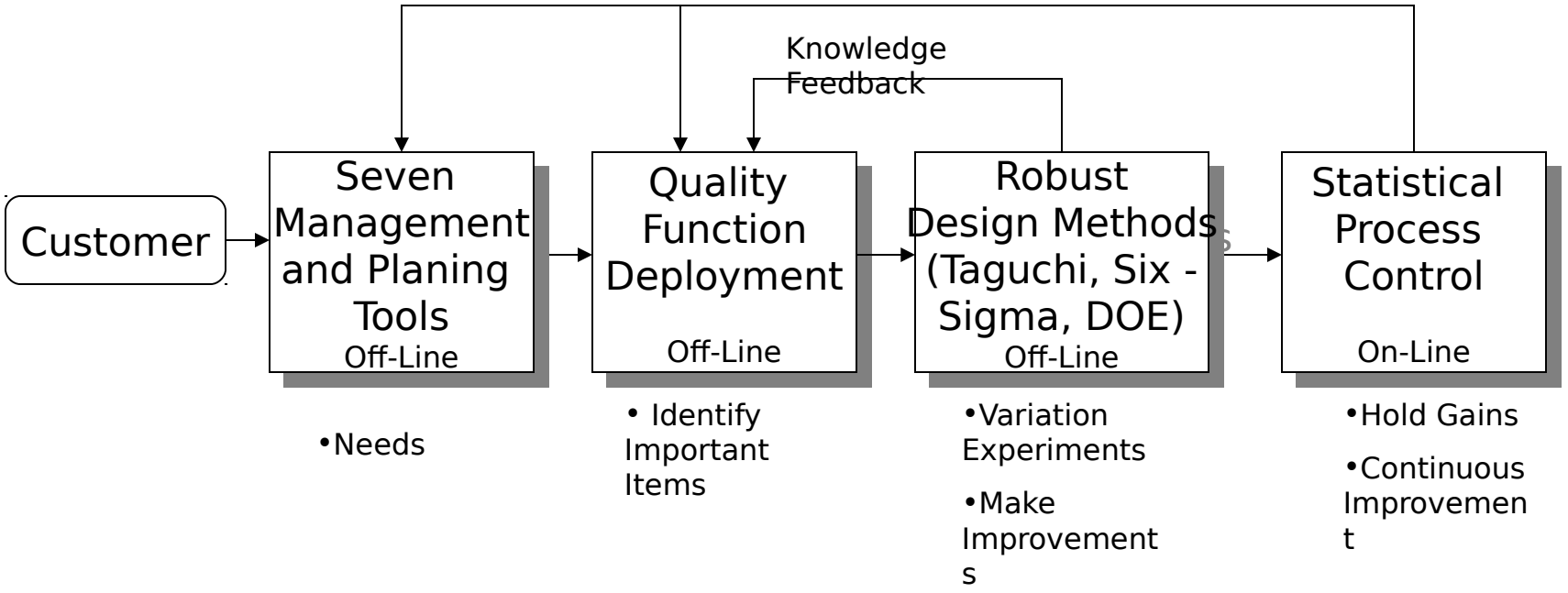
The Quality Engineering Process provides Recomposition



Having heard the “voice of the customer”, QFD prioritizes where improvements are needed; Taguchi provides the mechanism for identifying these improvements

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Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

for
Modern Systems Engineering

- Establish and Specify value: Value is defined by customer in terms of specific products & services, preferably as a Benefits to Cost Ratio (BCR)
- Identify the value stream: Map out all end-to-end linked actions, processes and functions necessary for transforming inputs to outputs to identify and eliminate waste (Value Stream Map or VSM)
- Make value flow continuously: Having eliminated waste, make remaining value-creating steps “flow”
- Let customers pull value: Customer’s “pull” cascades all the way back to the lowest level supplier, enabling just-in-time production
- Pursue perfection: Pursue continuous process of improvement striving for perfection

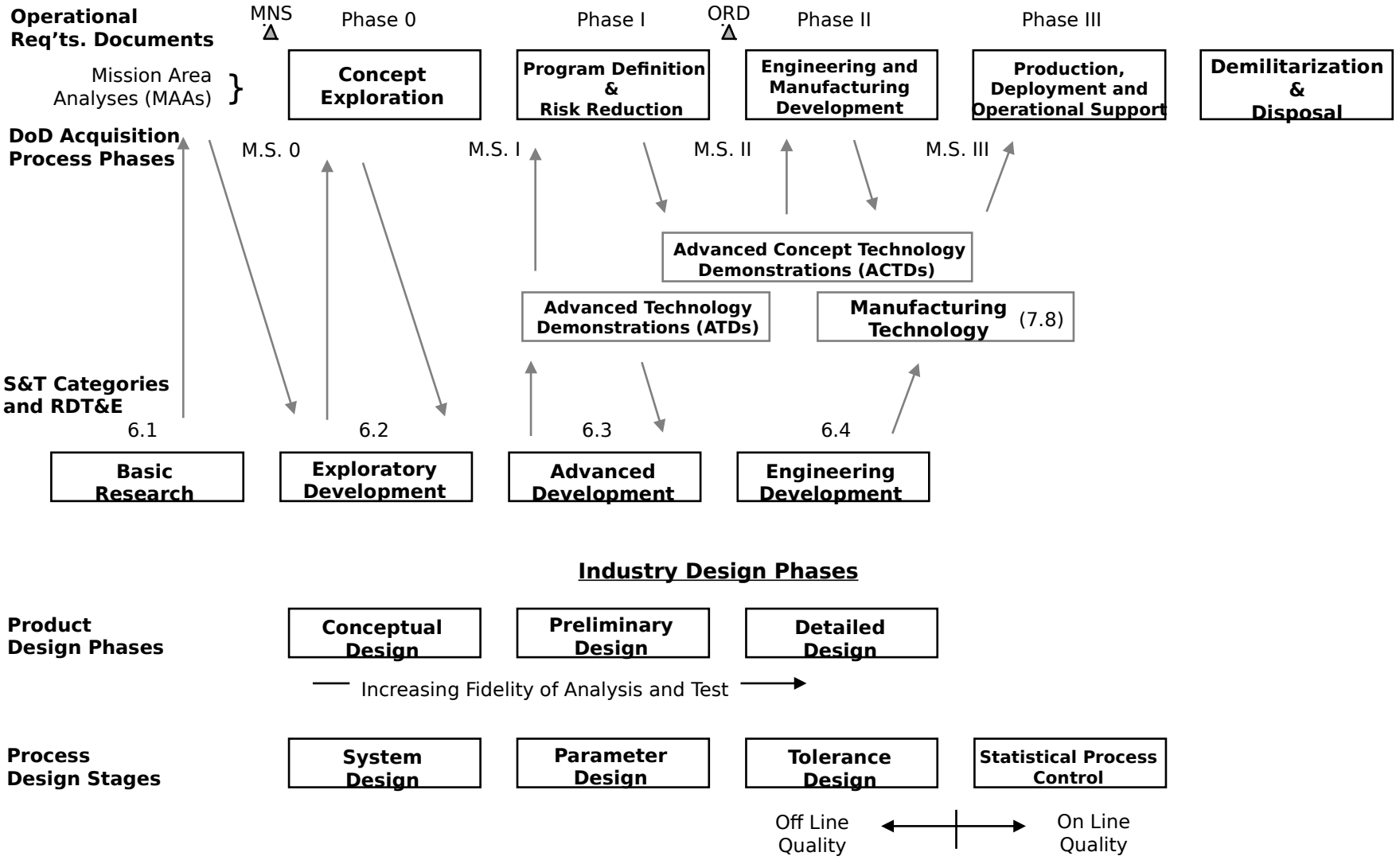
Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Source: James Womack and Daniel T. Jones, *Lean Thinking* (New York: Simon & Schuster,

Systems and Quality Engineering Activities

- *Value* is established based on *Systems Engineering* activities, such as requirements definition and functional analysis and allocation, and *Quality Engineering* activities, such as use of the seven management & planning tools and Quality Function Deployment (QFD) to *Define the Problem* and *Establish Value*, through the identification of an Overall Evaluation Criterion (OEC)
- The *Value Stream* is next determined through system synthesis & analysis for *Generating and Evaluating Alternatives* for establishing customer focused life cycle activities along a timeline, often domain or agency specific
- Make *Value Flow* through decision-making to track, system analyze and control the OEC periodically along the life cycle process, e.g. *earned Value*,
- *Let Customers Pull Value* to apply the Lean Principles throughout the *System Work Breakdown Structure (WBS)* to sub-contractors, vendors and suppliers, e.g. the Supply Chain Integration
- *Pursue Perfection* is to apply robust design and 0ptimization approaches for *Process Improvement* toward attaining Six Sigma, which is accomplished by *shifting the mean to the target* and *variability reduction* , e.g. Statistical Process Control techniques

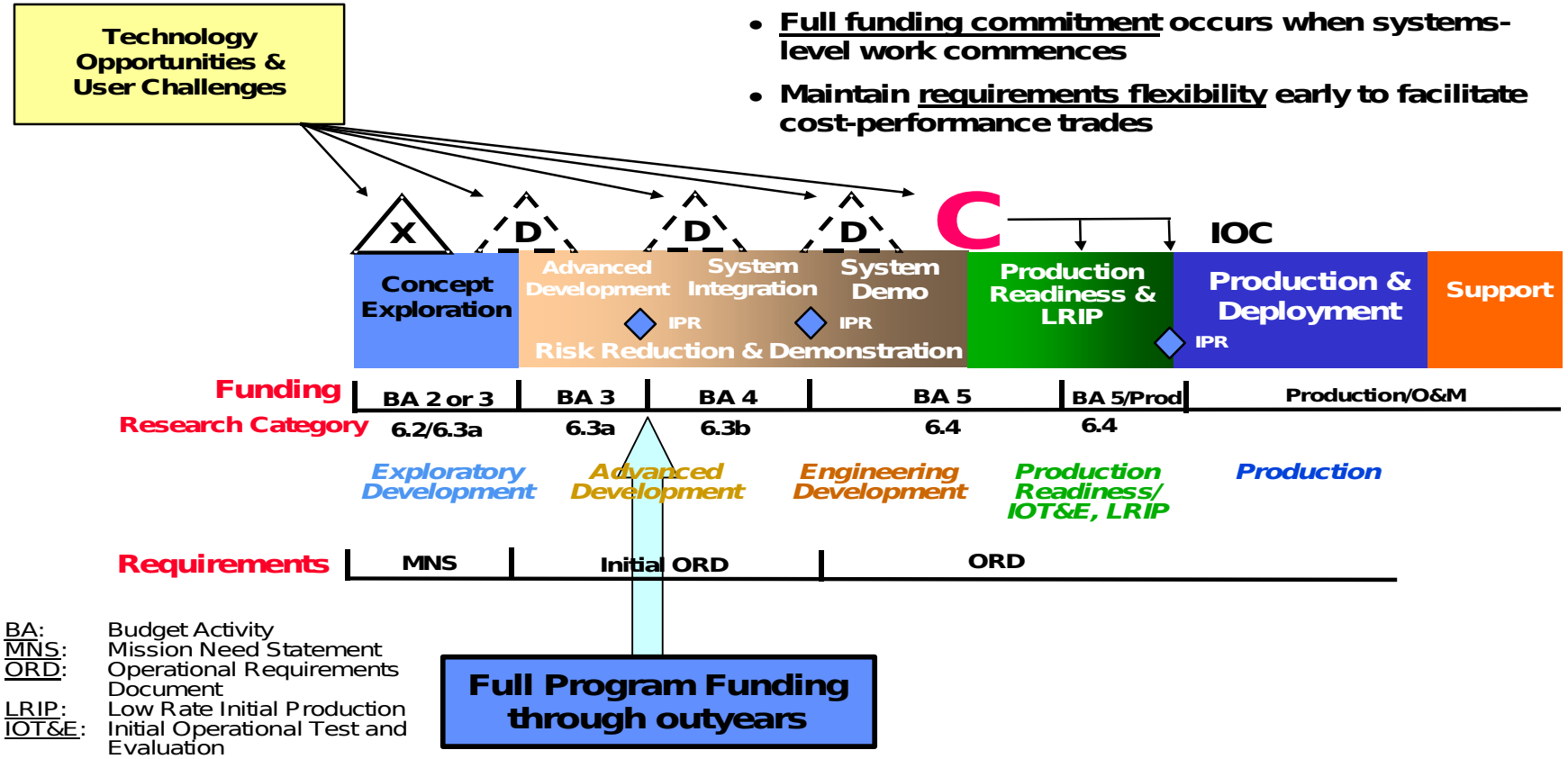
The Relationships between Requirements, DoD Acquisition, RDTE, and Industry Design Processes



Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

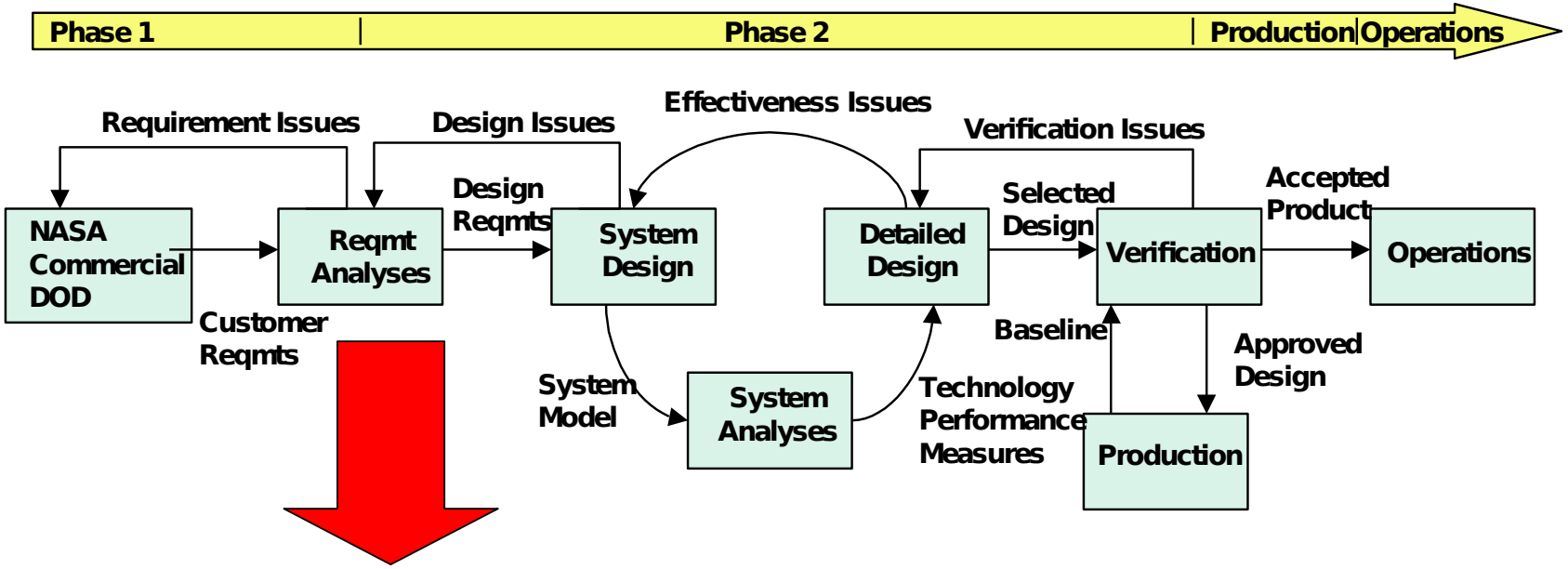
System, the Requirements Generation System, and the PPBS
(Latest DoD 5000.2)

FUNDING & REQUIREMENTS



Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

NASA's Life Cycle Process Model
(2nd Generation RLV Risk Reduction Solicitation)



Safety

Reliability

Affordability

Mission Performance

→ Refine for Commercial Convergence → Define Priority Risk Reduction Needs → Define Scale, Fidelity, Test Environment for Tech Demos → Enable Full Scale Development With 20% Margin

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Aircraft
Overall Evaluation Criterion (OEC)

$$OEC = \frac{\alpha(A_i) + \beta(MCI) + \delta(S_i)}{\varphi(LCC)}$$

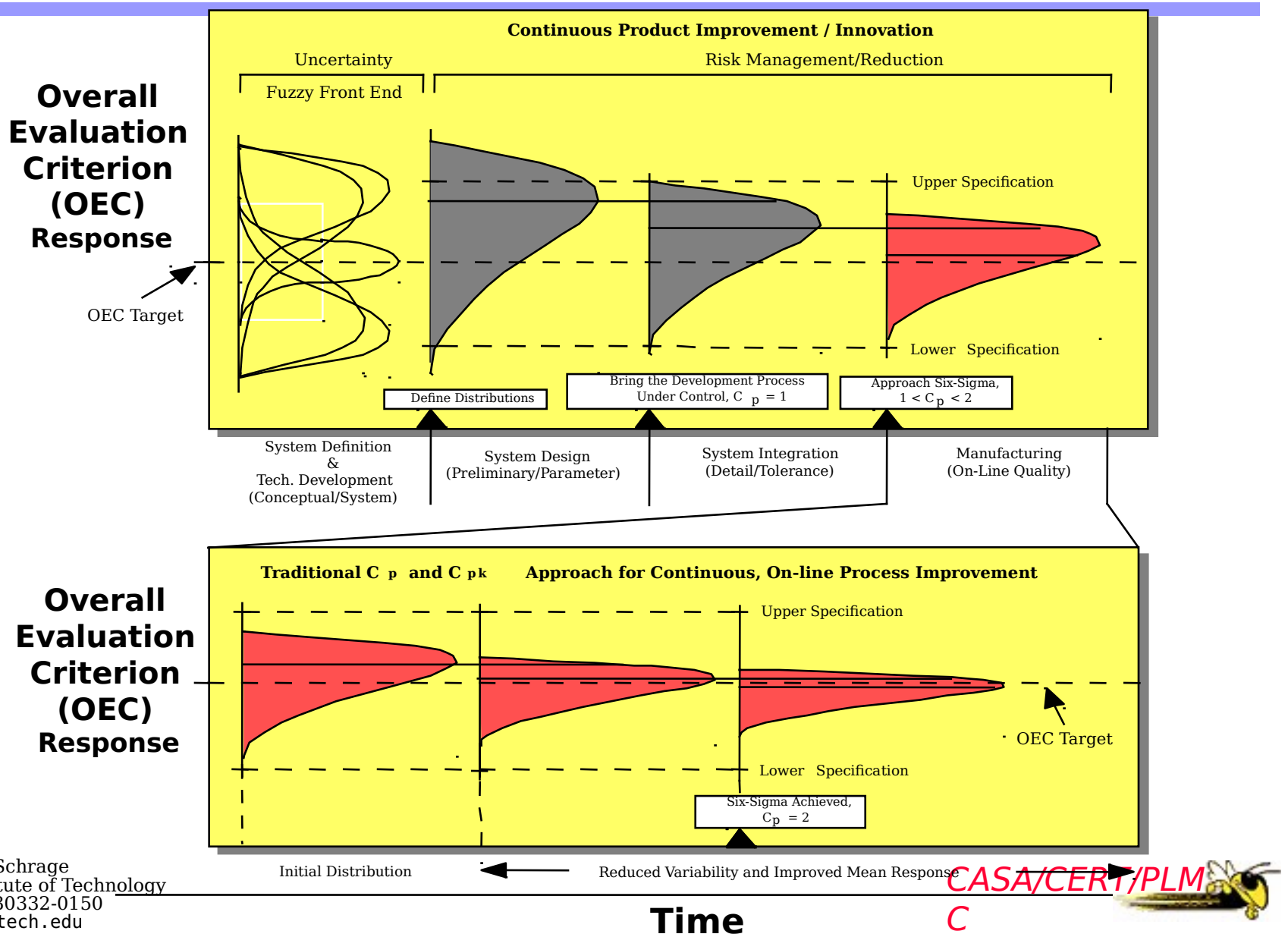
$$A_i = \frac{MTBF}{MTBF + MTTR}$$

$$MCI = \frac{Payload * (Distance / Time)}{W_{Empty} + W_{Fuel}}$$

$$S_i = 1 - P_D P_H P_K \qquad LCC = RDTE + PC + O\&S + DC$$

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Coninuous RDS along the System Life Cycle to link the "fuzzy front end" to the "process capability approache



Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

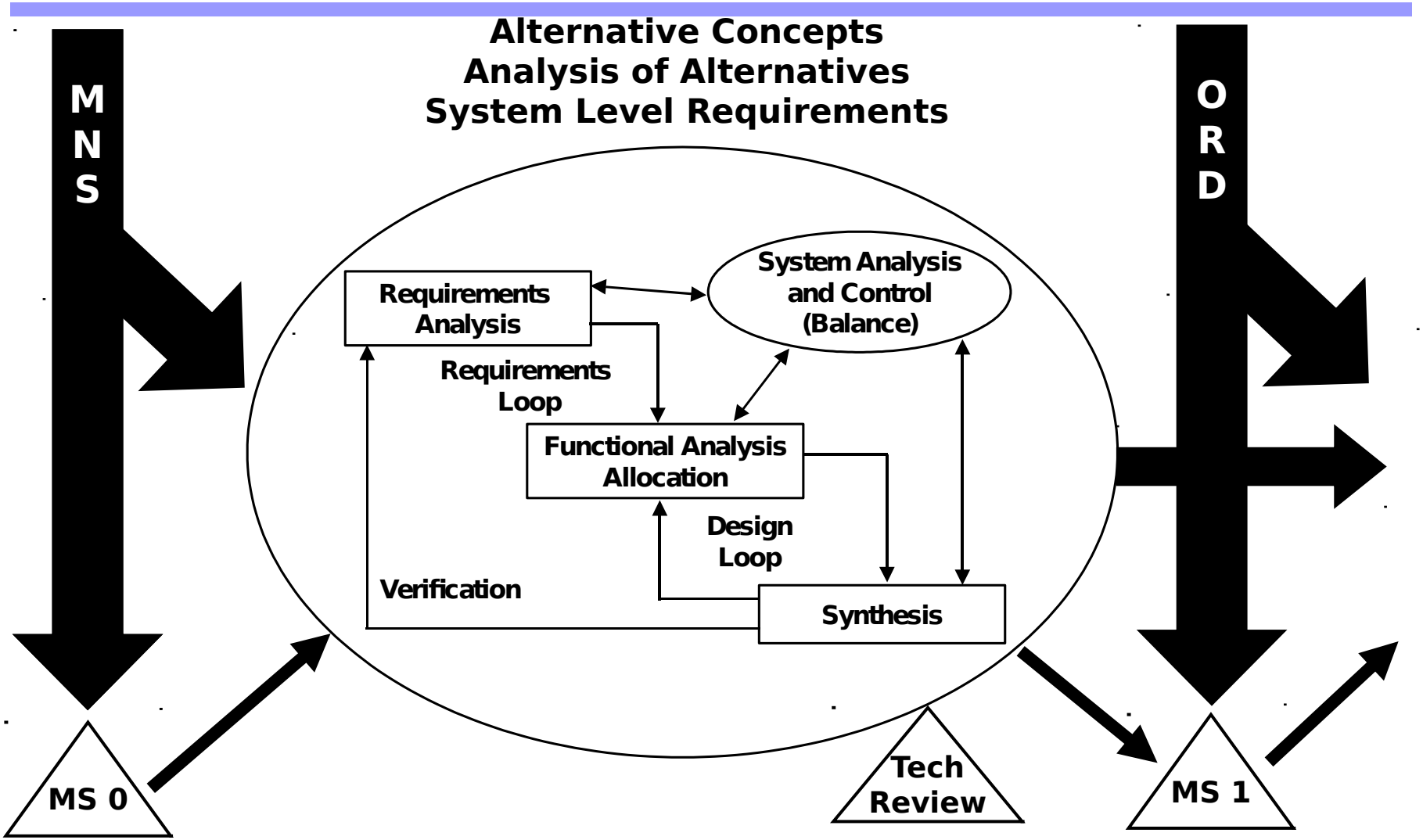
The VSLCDE- Key Characteristics

The purpose of VSLCDE is to facilitate design decision- making over time (at any level of the organization) in the presence of uncertainty, allowing affordable solutions to be reached with adequate confidence. It is a research testbed.

- ***Virtual*** . . . Simulation-based system life-cycle prediction
- ***Stochastic*** . . . Time-varying uncertainty is modeled; temporal decision-making
- ***Life-Cycle*** . . . the design, engineering development, test, manufacture, flight test, operational simulation, sustainment, and retirement of a system. The operational simulation includes virtual testing, evaluation, certification, and fielding of a vehicle in the existing infrastructure, and tracking of its impact on the economy, market demands, environment.
- ***Design*** . . . Implies that the environment's main role is to provide knowledge for use by decision-makers, especially for finding robust solutions
- ***Environment*** . . . Implies the support of geographically distributed analyses and people through collaboration tools and data management

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Concept Exploration

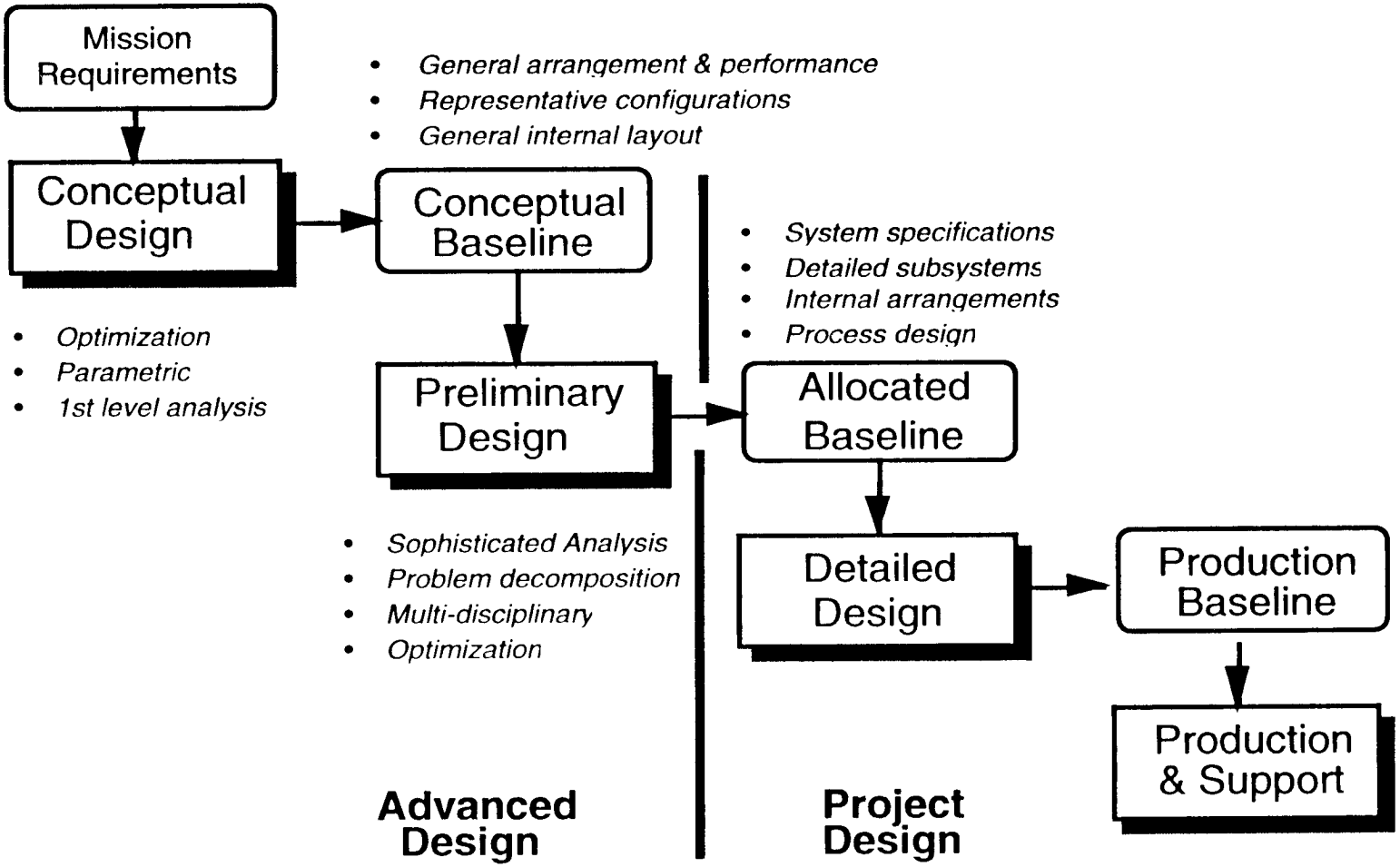


Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

What is IPPD?

- *Integrated Product/Process Development (IPPD)* is a management methodology that incorporates a systematic approach to the *early integration* and concurrent application of all the disciplines that play a part throughout a system's life cycle (Technology for Affordability: A Report on the Activities of the Working Groups to the Industry Affordability Executive Committee, The National Center for Advanced Technologies (NCAT), January 1994)
- IPPD evolved out of the commercial sector's assessment of what it took to be world class competitive in the 1980s
- The DoD has required IPPD and the use of IPTs where practical throughout the DoD Acquisition Process for Major Systems (DoD 5000.2R)
- Conduct of IPPD requires Product/Process Simulation using *Probabilistic Approaches*

Traditional Design & Development Using only a Top Down Decomposition *Systems Engineering* Process



Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
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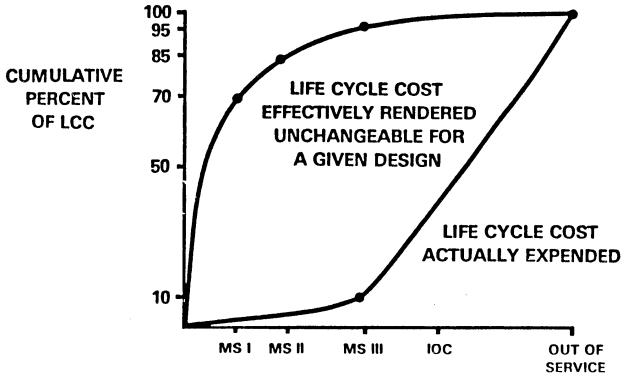
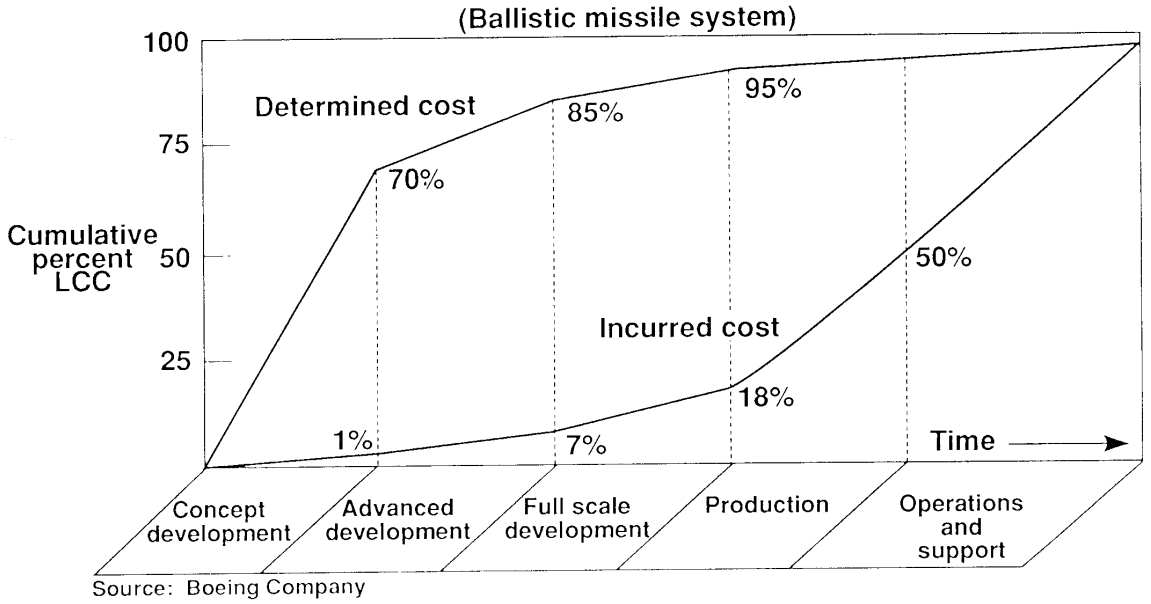
Life Cycle Cost Gets Locked In Early for Complex Systems using only Systems Engineering Decomposition

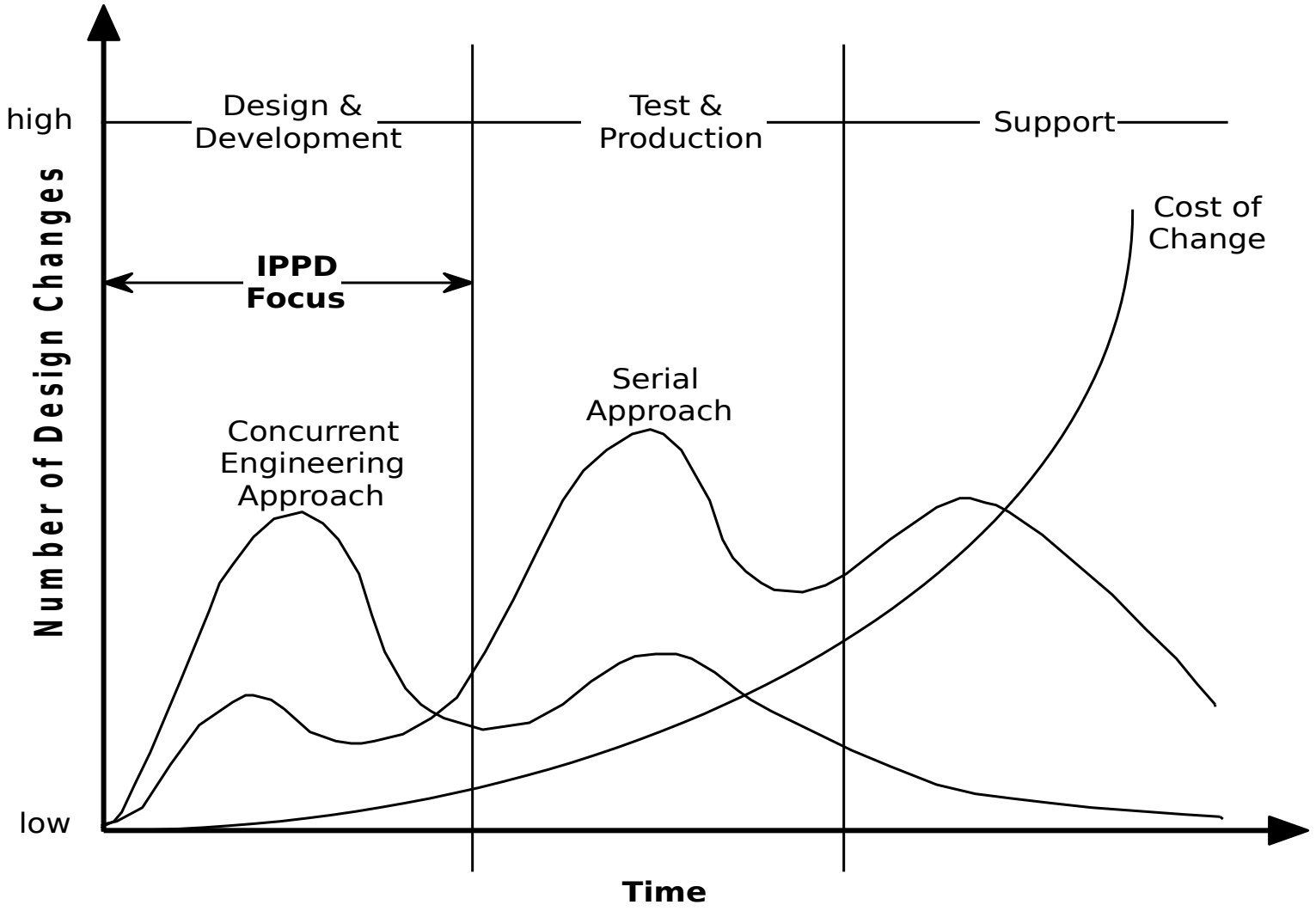




Source: Boeing Company

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Approach



Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
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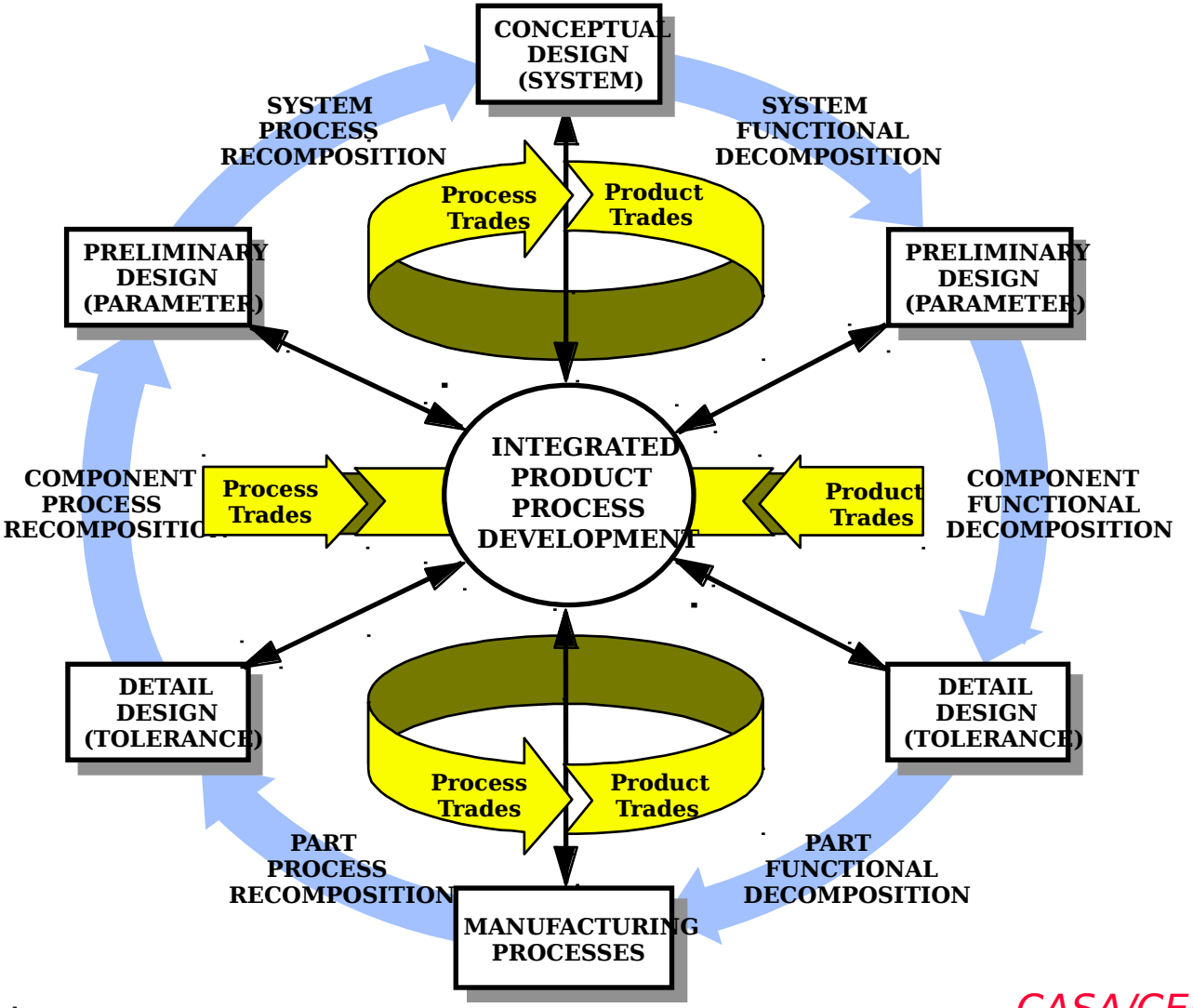
IPPD Requires the Computer Integration of Product and Process Models and Tools for System Level Design Trades and Cycle Time Reduction



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Georgia Institute of Technology
Atlanta, GA 30332-0150
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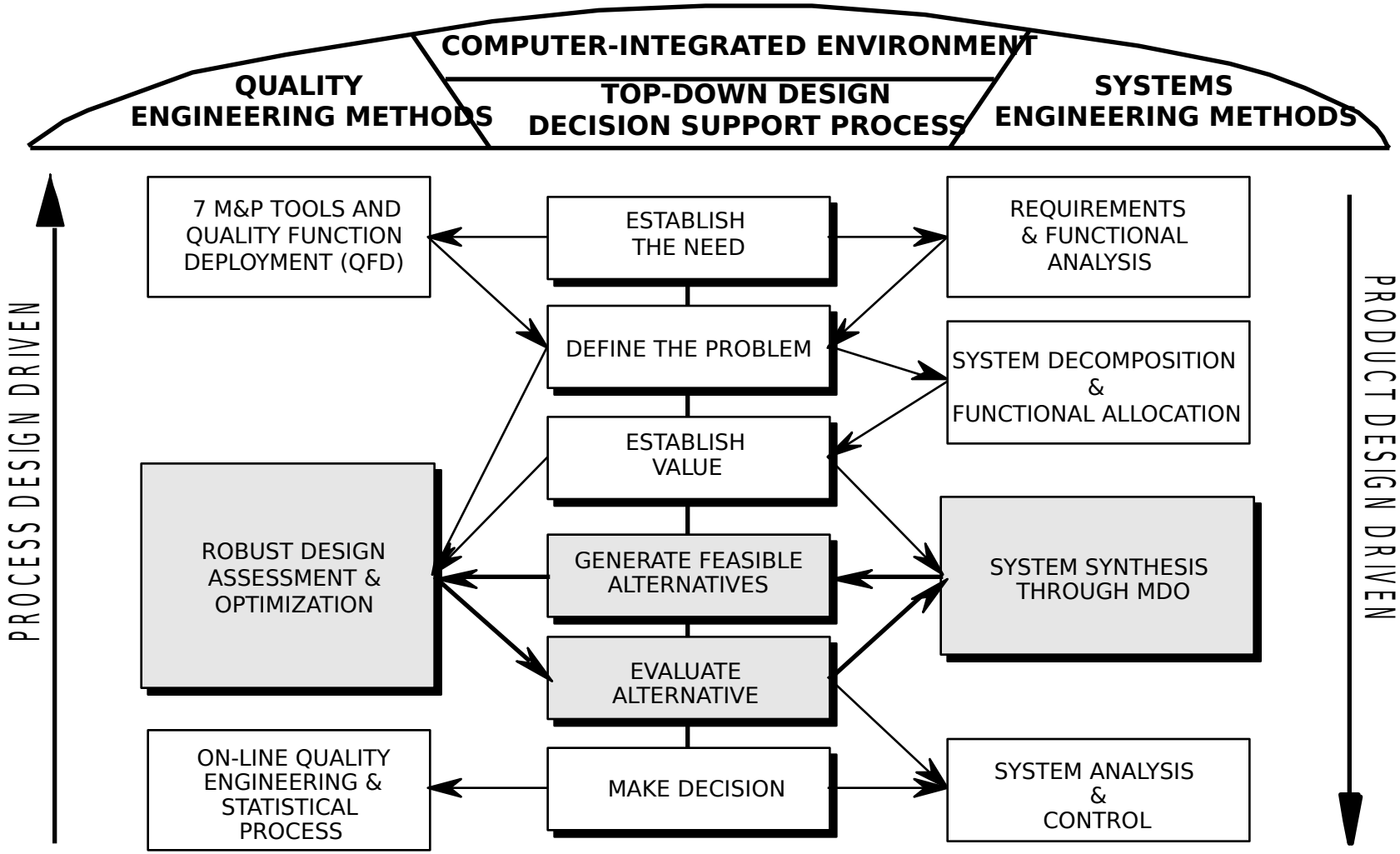
Georgia Tech Generic IPPD Methodology



Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
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Georgia Tech Generic IPPD Methodology

- Methodology provides a *procedural* design (trade-off iteration) approach based on four key elements:
  - *Systems Engineering Methods and Tools* (Product design driven, deterministic, decomposition approaches; MDO is usually based on *analytic* design approach)
  - *Quality Engineering Methods and Tools* (Process design driven, nondeterministic, recomposition approaches; MDO is usually based on *experimental* design approach)
  - *Top Down Design Decision Process* Flow (Provides the design trade-off process required for Complex Systems)
  - *Computer Integrated Design* Environment(*Information Technology* driven to provide a collaborative interactive environment)
- Methodology has been implemented through *Robust Design Simulation (RDS*) for a number of applications

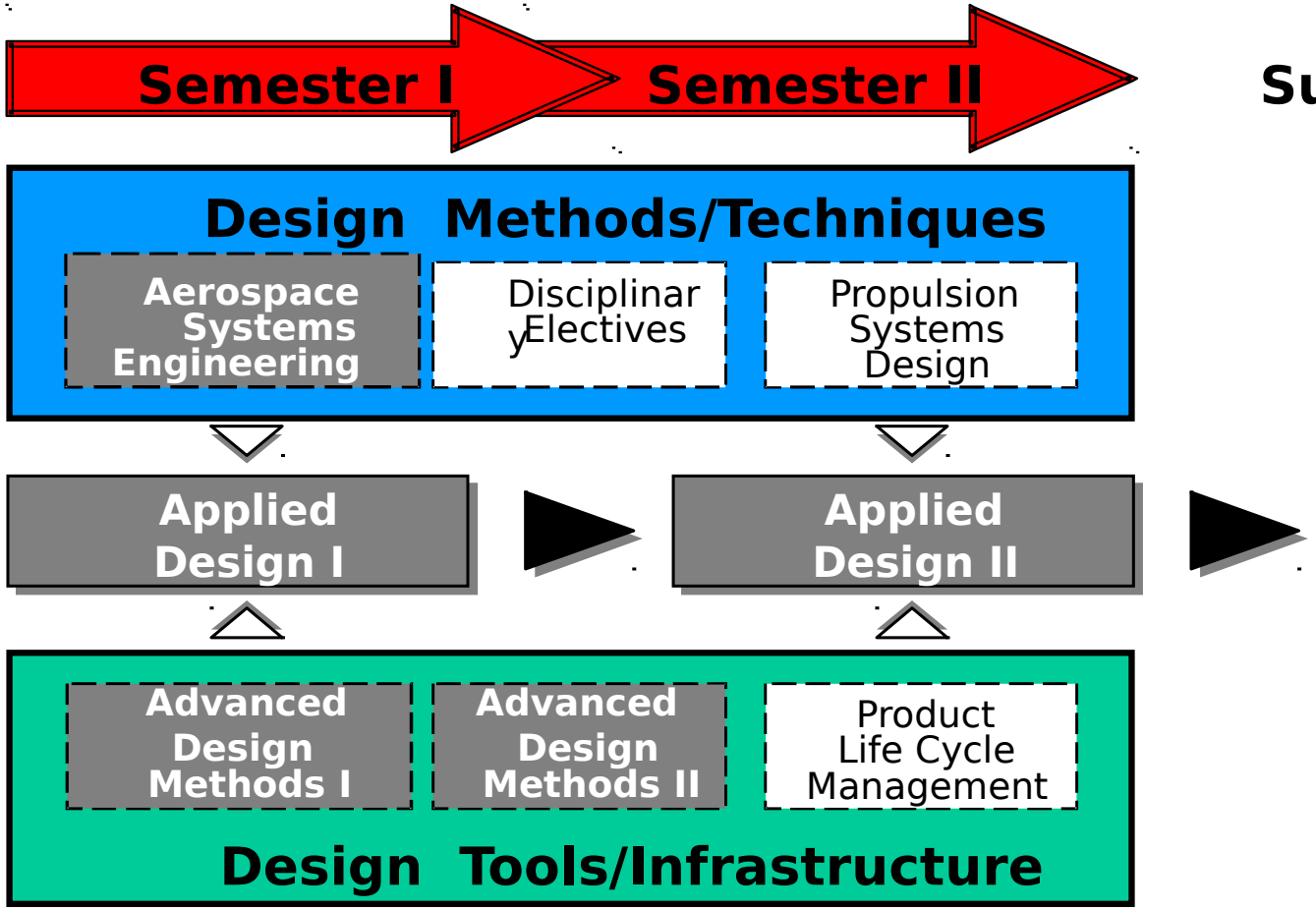
Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Aerospace Systems Design & Analysis

- Initiative kicked of in the early 1990s *based on IPPD Approach*
- *Education executed* in the School of Aerospace Engineering and *research program executed* through the Center for Aerospace Systems Analysis (CASA) and its two major Laboratories, The Aerospace Systems Design Laboratory (ASDL) and The Space Systems Design Laboratory (SSDL)
- Currently has approximately 140 graduate students with over 80 % U.S. citizens – *top students from top universities*
- Research Program currently at approximately $6M per year including four faculty and 15 research engineers, plus 100 GRAs
- Program is built on *probabilistic approaches* for implementing IPPD through Robust Design Simulation
- Goal is to *develop, verify and validate*, in collaboration with industry and government, a Virtual Stochastic Life Cycle Design Environment (VSLCDE)

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Program in Aerospace Systems Design & Analysis



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Georgia Institute of Technology
Atlanta, GA 30332-0150
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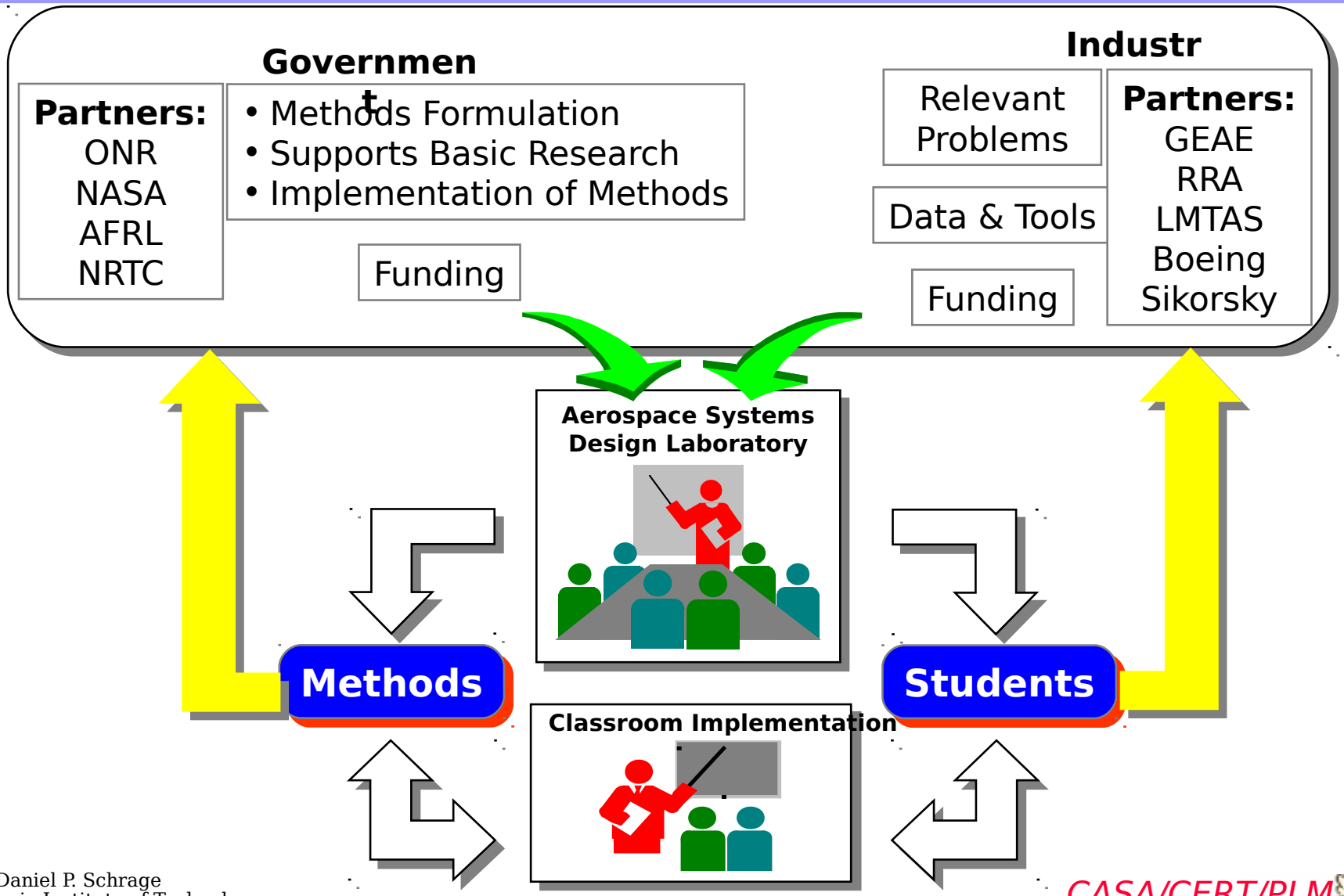
CASA/CERT/PLM
C

Aerospace Systems Design Integrated Education & Research Philosophy



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Georgia Institute of Technology
Atlanta, GA 30332-0150
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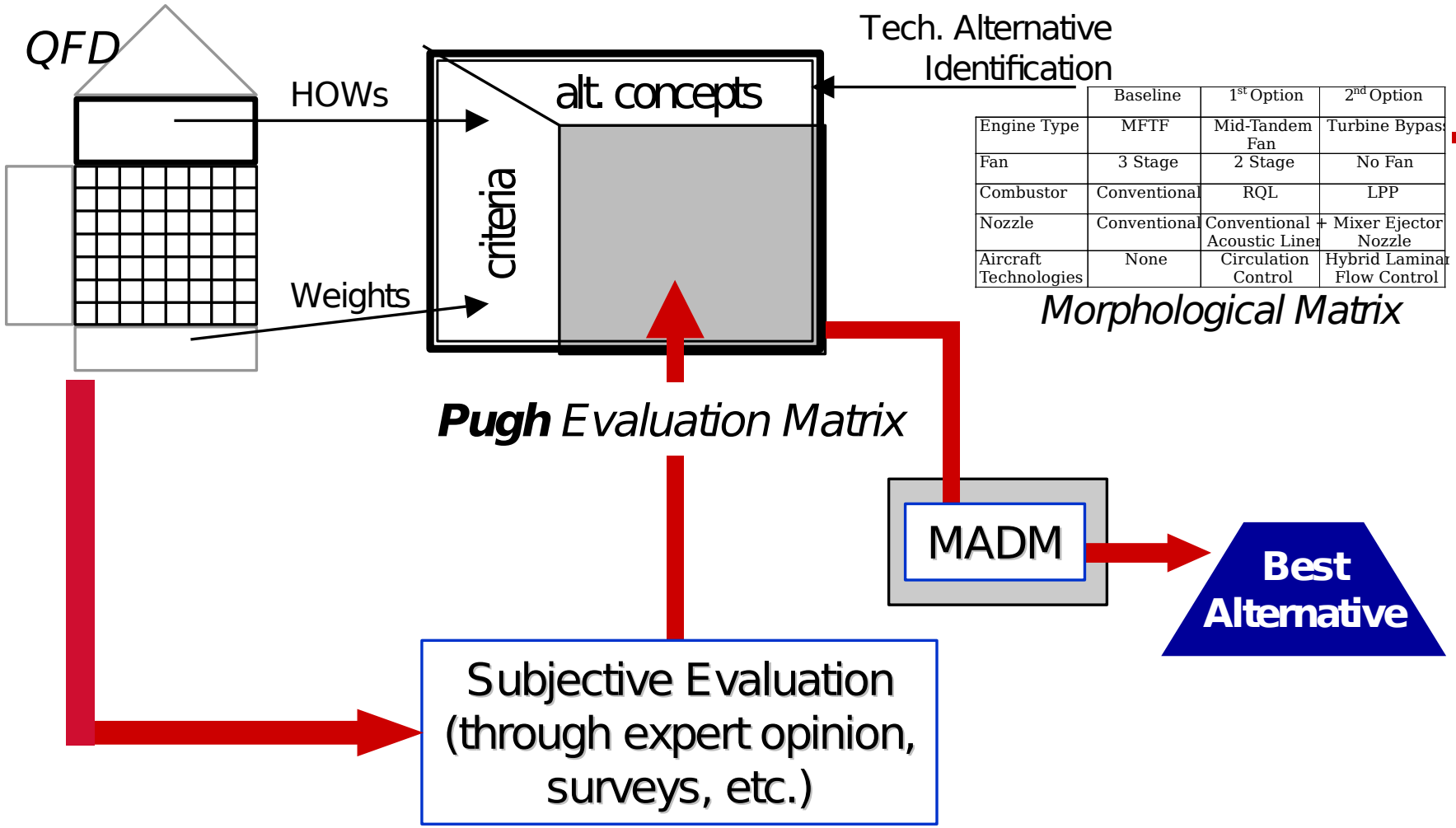
Complex System Formulation Initially taught in Aerospace Systems Engineering using an Integrated Set of Simple Tools



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Georgia Institute of Technology
Atlanta, GA 30332-0150
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Current Complex System Formulation Projects in Aerospace Systems Engineering Course (Fall 2003)

1. AIAA Graduate Student Missile Design Competition **"Multi Mission Cruise Missile Design"**
2. AHS Student Design Competition for **"Design Certification Mountain Rescue Helicopter"**
3. NASA Identified Complex System of Systems Problem: **"Future Air Transportation Architecture - A System of Systems Problem**"
4. NASA Specific Complex System Problem: "**Space Shuttle Derivative: What it takes to make it Safe and Flyable**"
5. NASA Identified Complex System Problem: **"Two Stage Turbine Based Combined Cycle (TBCC) Space Access Launch Vehicle"**
6. NASA Aerospace Vehicle Systems Technology Office Student Design: **"Quiet Supersonic Business Jet and Transport"**

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Current Complex System Formulation Projects in Aerospace Systems Engineering Course (Fall 2003)

7. Homeland Security and Coast Guard Initiative: **"Feasibility of Accelerating the Integrated Deepwater System (IDS): A Network Centric Complex System"**
8. Missile System Technical Committee: **"Long Range Liquid Target Vehicle (LRLTV)"**
9. University Student Design Competition: **"International Micro Aerial Vehicle (MAV) Competition"**
10. Complex System Formulation for: **"Boeing 7E7 "Dreamliner" Commercial Transport"**
11. Complex System Formulation for : **"Morphing UCAV Aircraft"**
12. NASA Aerospace Vehicle Systems Technology Office Student Design Competition for: **"Unmanned Air Vehicle Systems and Technologies: Replacement for Helios"**

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
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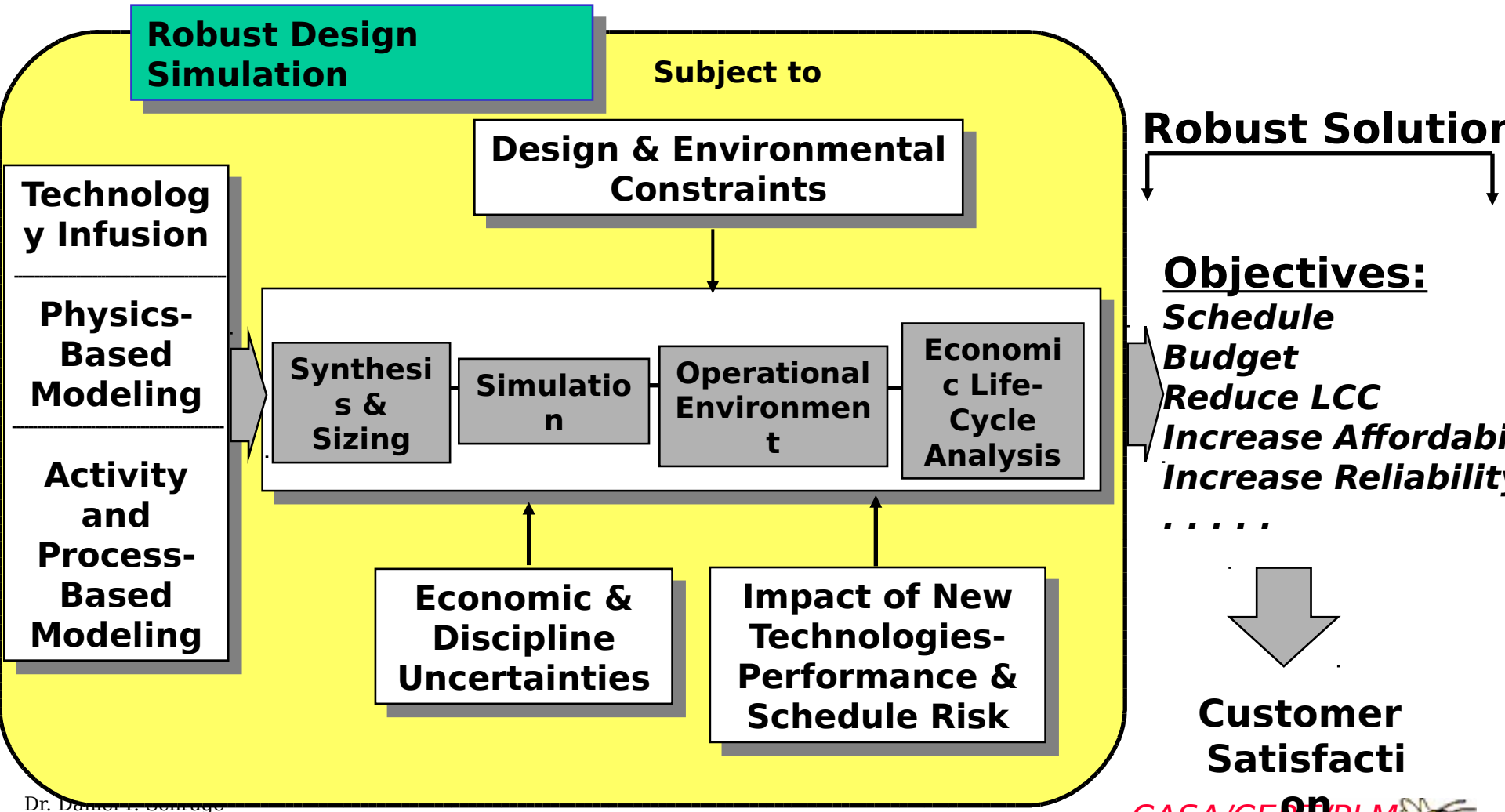
Roadmap to Affordability Through Robust Design Simulation



Dr. Daniel A. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
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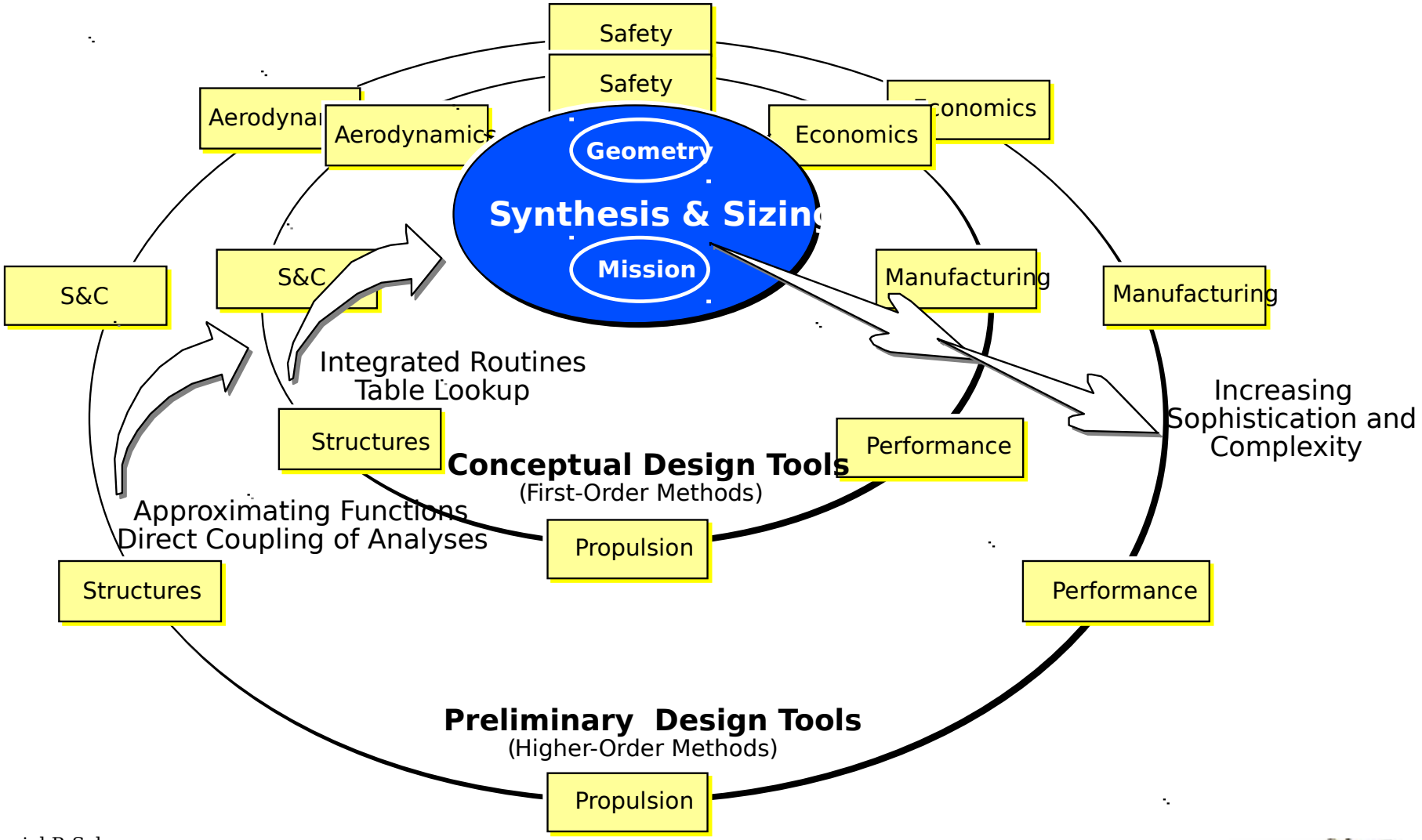
is the key for translating Mission into Geometry



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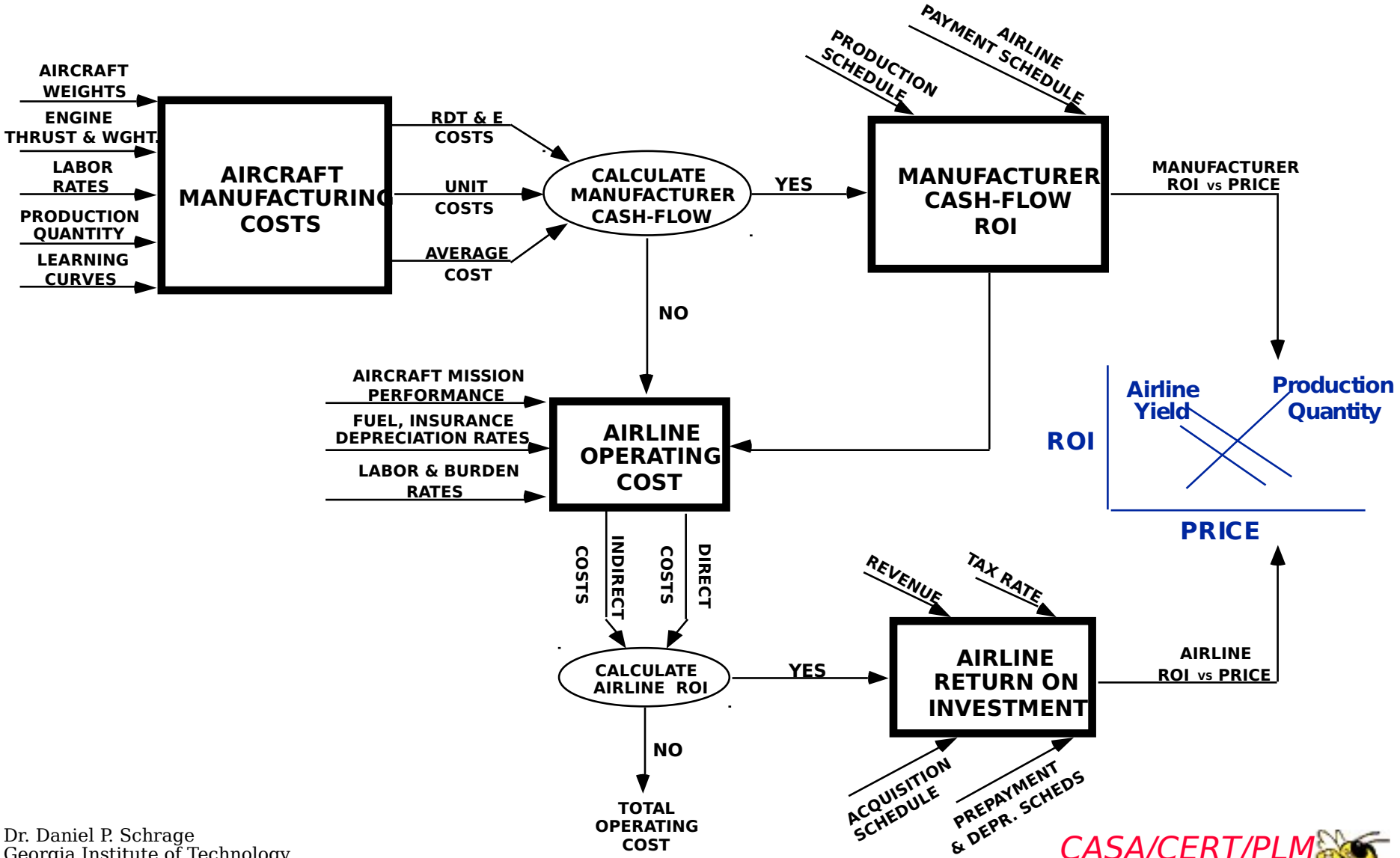
(ALCCA) - including Economic Cash Flow Analysis



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Georgia Institute of Technology
Atlanta, GA 30332-0150
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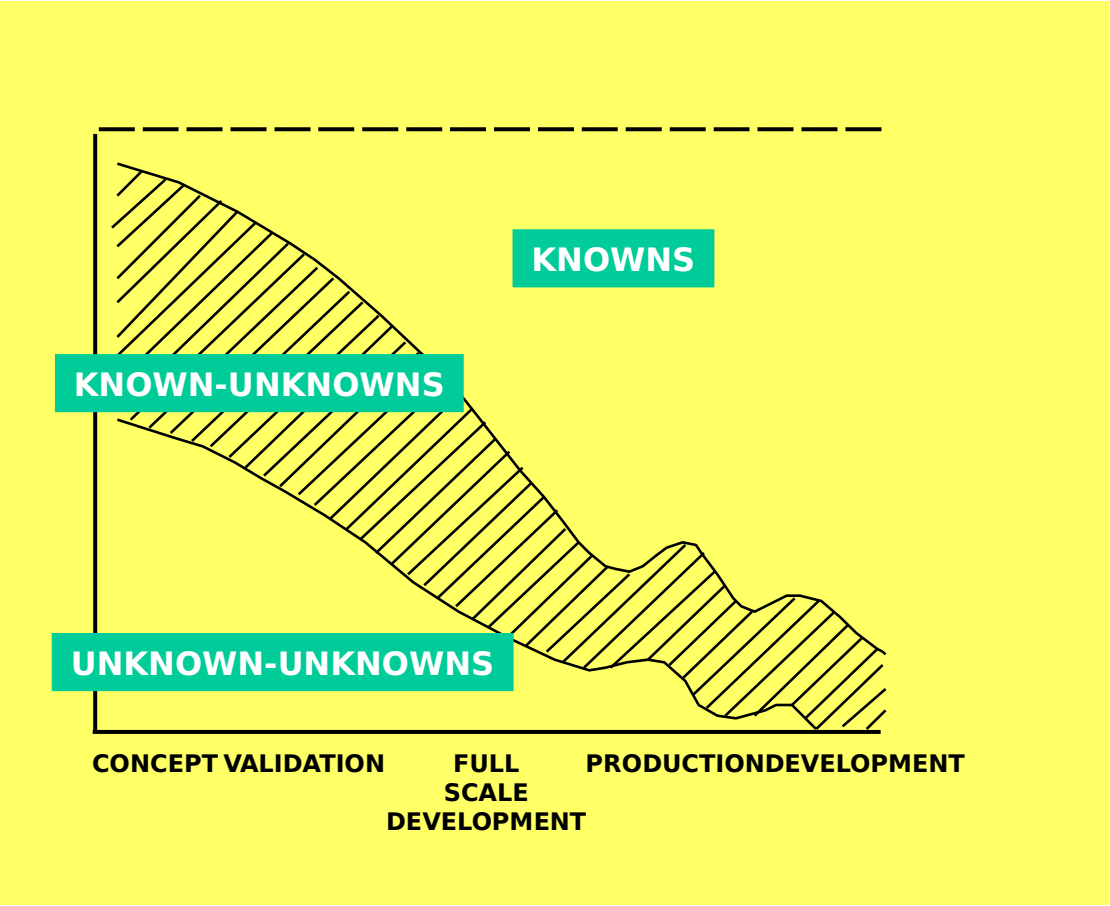
Risk & Uncertainty are Greatest at the Front

Known Unknowns correspond to Risk and Known Probability Distrib



UnKnown Unknowns correspond to Uncertainty and Unknown Probabilit

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Georgia Institute of Technology
Atlanta, GA 30332-0150
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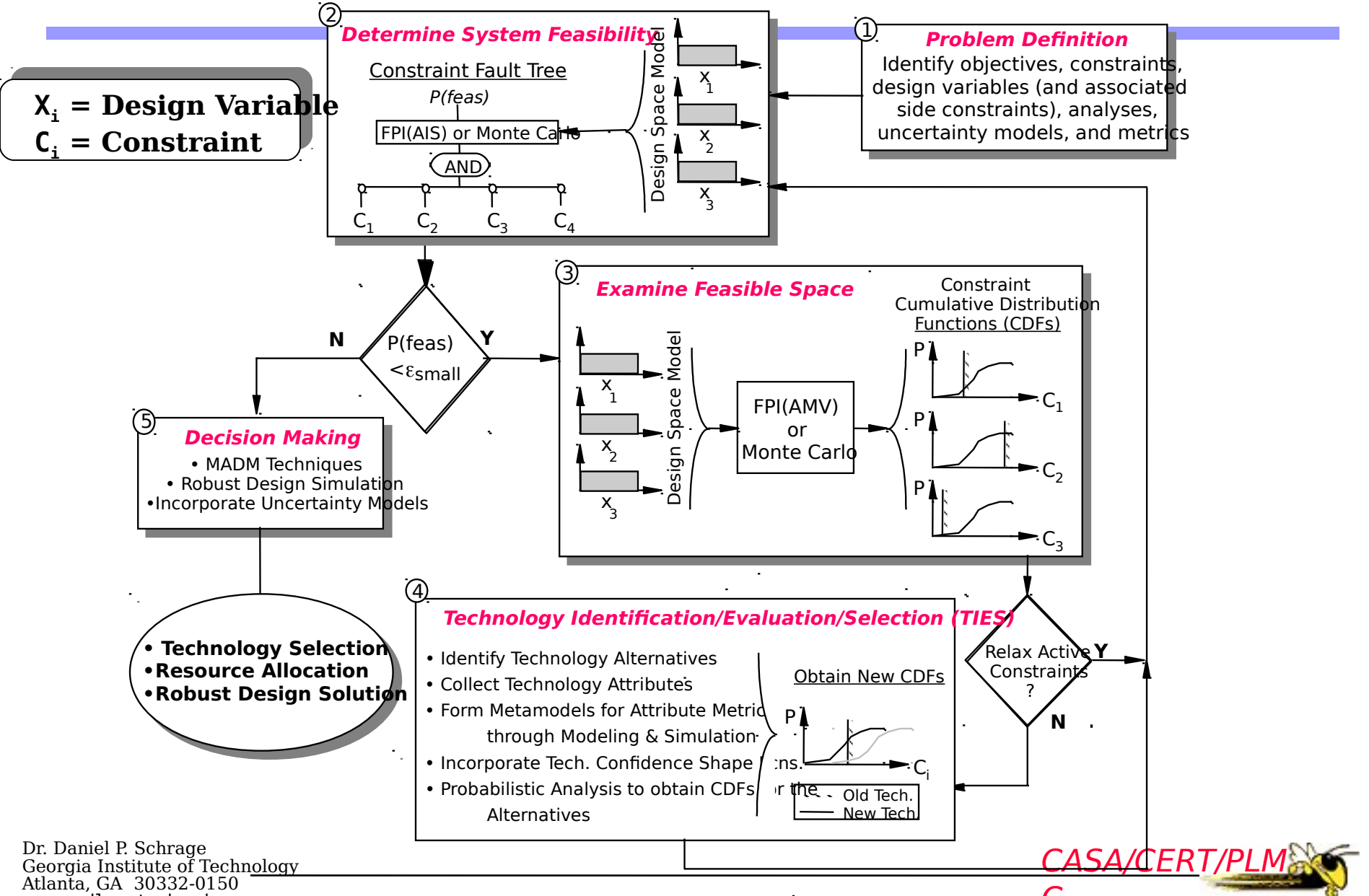
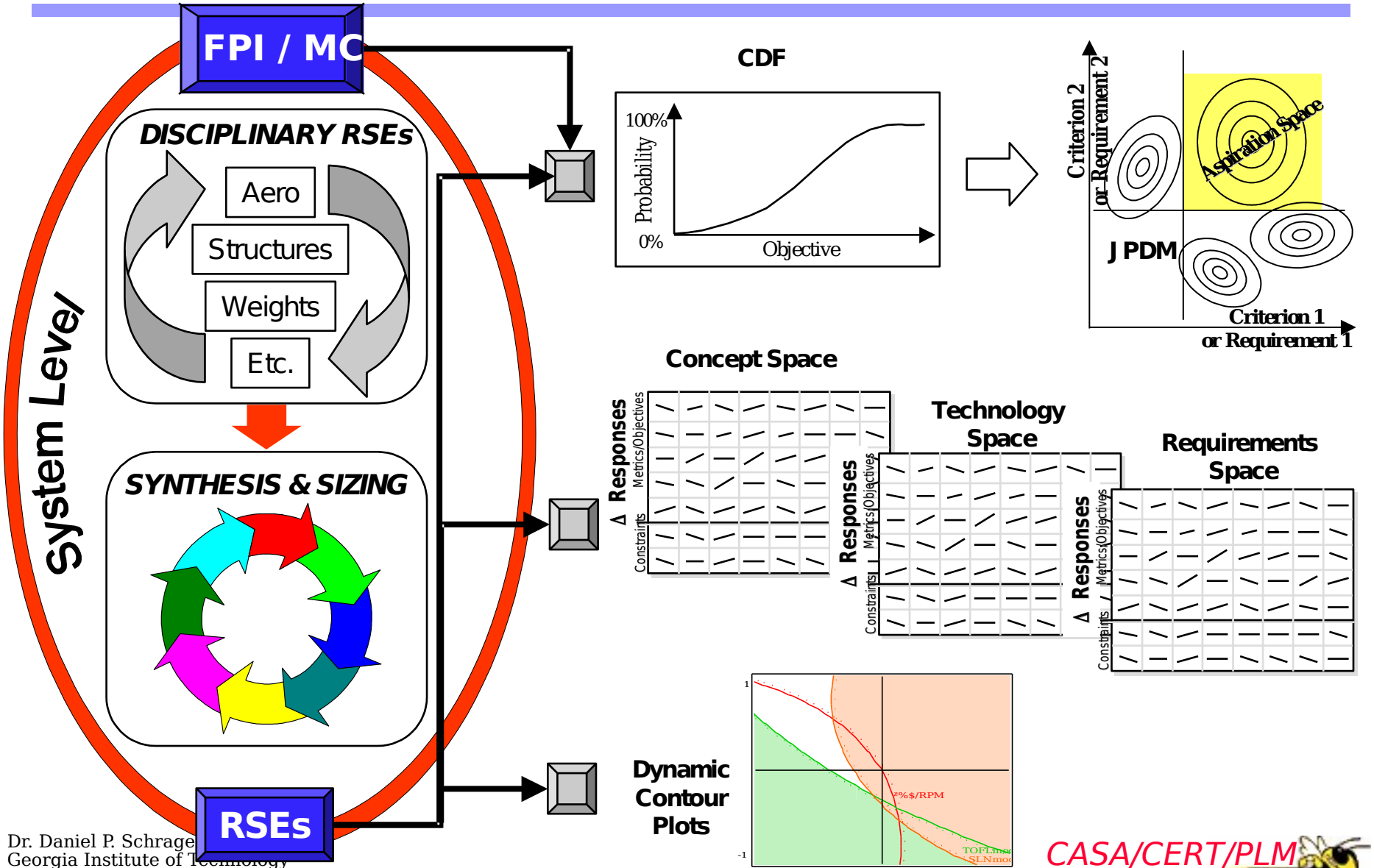
The Five Step RDS Process



Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Interactive RDS Environment



Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Two Examples on Application of IPPD Through RDS

System of Systems: CDSE Process for FCS FST Team in Phase I

Derivative Program: F-18C Conversion to F-18E/G

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

FST Process Methodology for FCS Phase I Concept Development & Systems Engineering

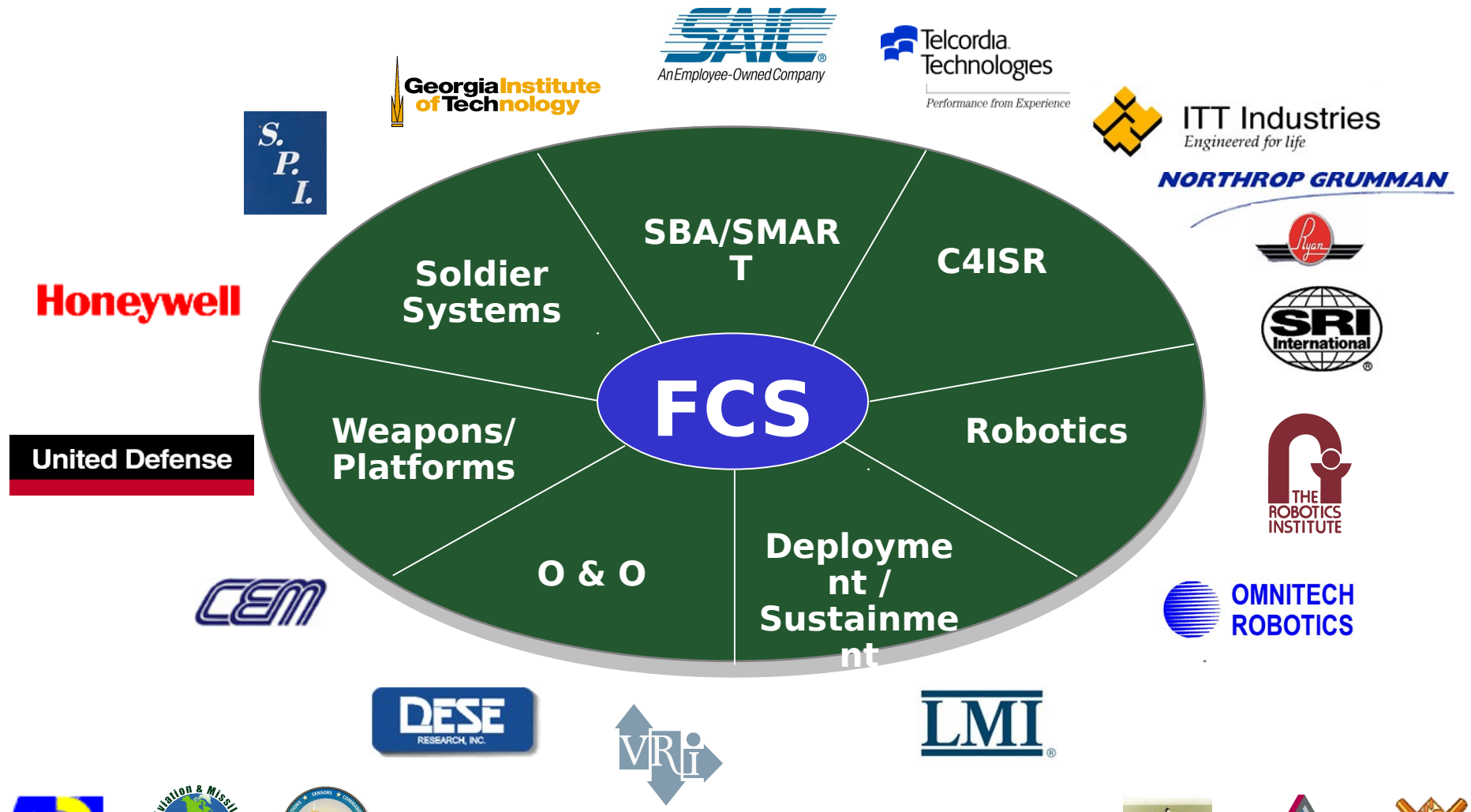
Methodology Incorporates IPPD Principles, QFD, Analysis, Engineering Simulation, Systems Engineering Tools, and Force-on-Force Simulation

(This presentation does not reflect the current thinking of the FCS LSI)

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

One of Four Teams in FCS Phase I

2408W-C07



Working Closely With Government L[illegible]

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Atlanta, GA 30332-0150
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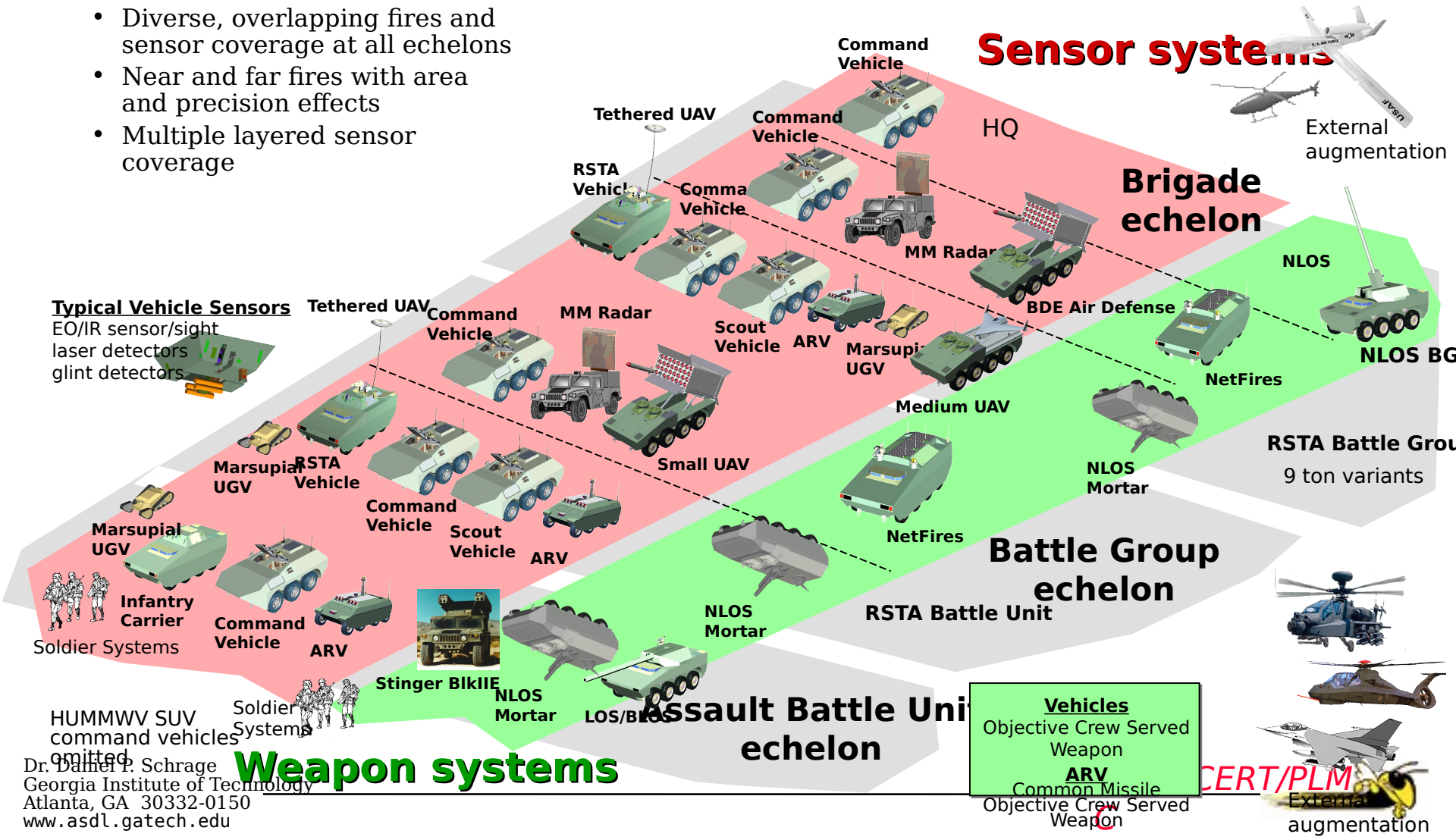
Network Centric System Design of a Lethal Brigade

The FST Brigade is designed to fight with precision fires and h

- Diverse, overlapping fires and sensor coverage at all echelons
- Near and far fires with area and precision effects
- Multiple layered sensor coverage



Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
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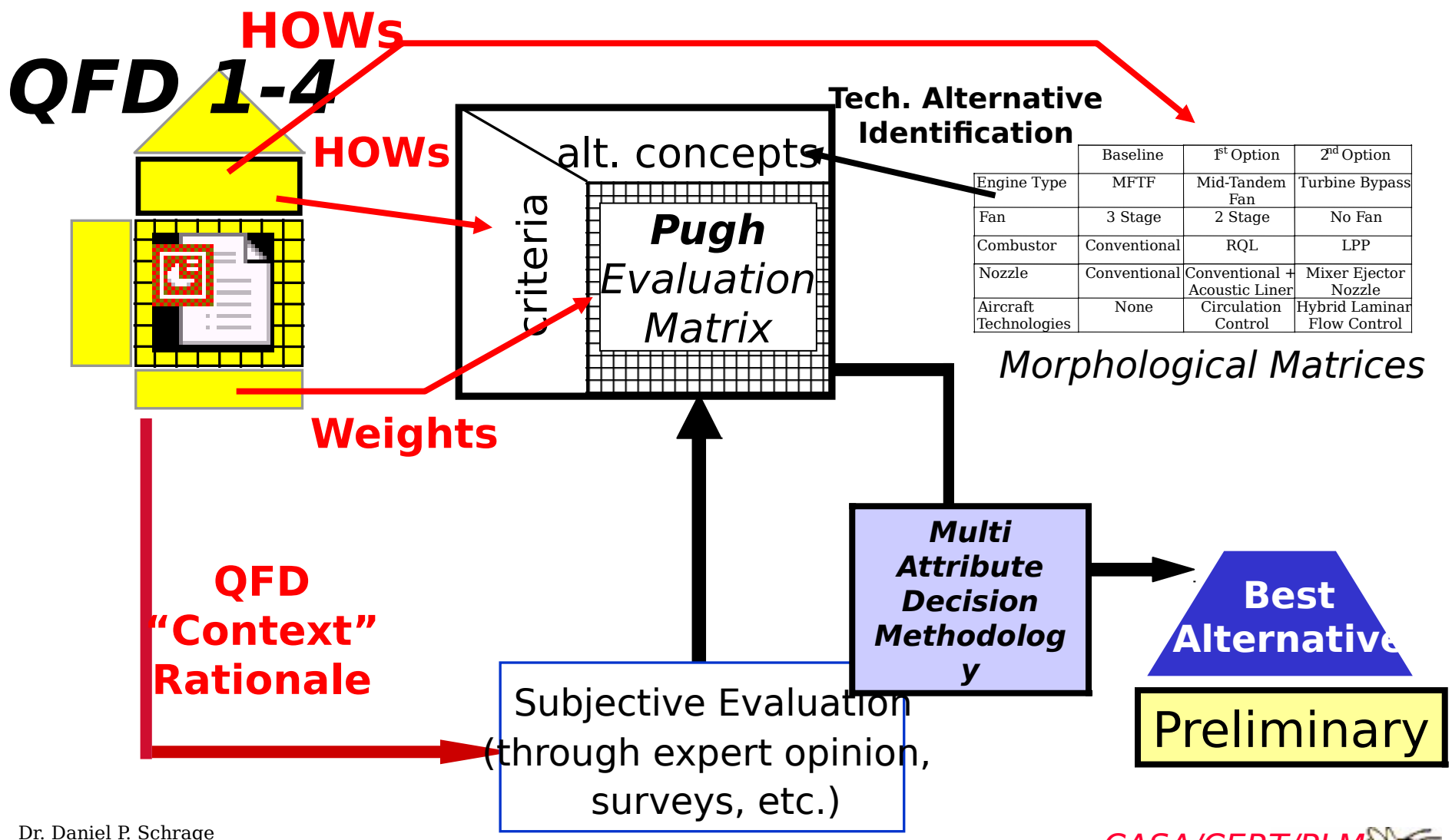
Systems Engineering (CDSE) Process

- Incorporates key aspects of modern systems engineering approaches, and lends itself to iteration
  - Requirements Flowdown
  - Engineering Trades / Analysis
  - Force Effectiveness Modeling and Simulation
  - Risk Mitigation
- Allows full exploration of need identification and problem definition, concept development, and concept selection—prior to system definition and design
- Facilitates group work and utilizes modern software based tools
- Allows full incorporation of increasingly detailed simulation-based analyses and designs
- Smoothly extends throughout engineering and manufacturing phases

Integration of QFD, Morph and Pugh Products Into CDSE Process

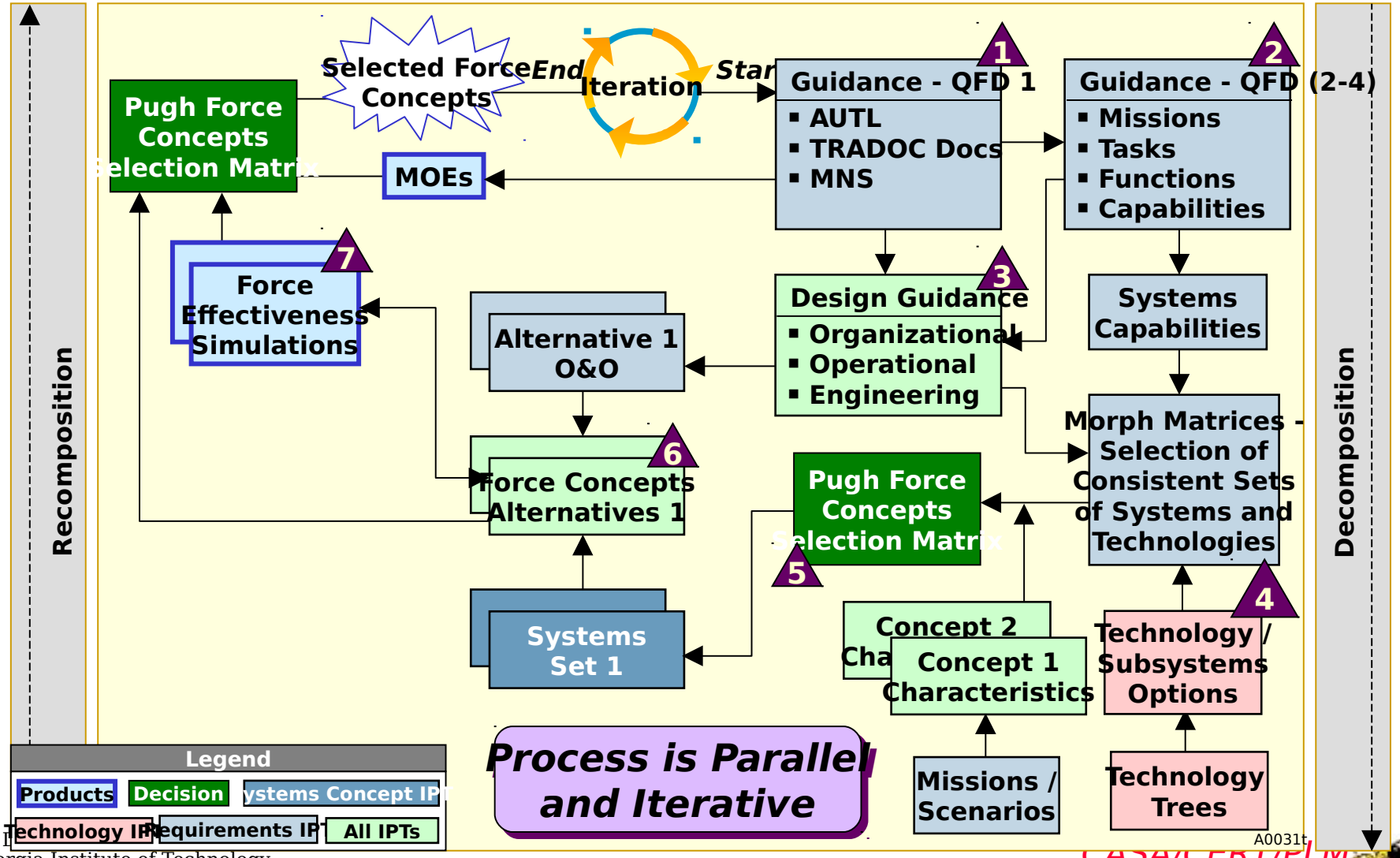


	Baseline	1st Option	2nd Option
Engine Type	MFTF	Mid-Tandem Fan	Turbine Bypass
Fan	3 Stage	2 Stage	No Fan
Combustor	Conventional	RQL	LPP
Nozzle	Conventional	Conventional + Acoustic Liner	Mixer Ejector Nozzle
Aircraft Technologies	None	Circulation Control	Hybrid Laminar Flow Control

Morphological Matrices

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Full Spectrum Total PGS Concept Development & Systems Engineering (CDSE) Process



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Atlanta, GA 30332-0150
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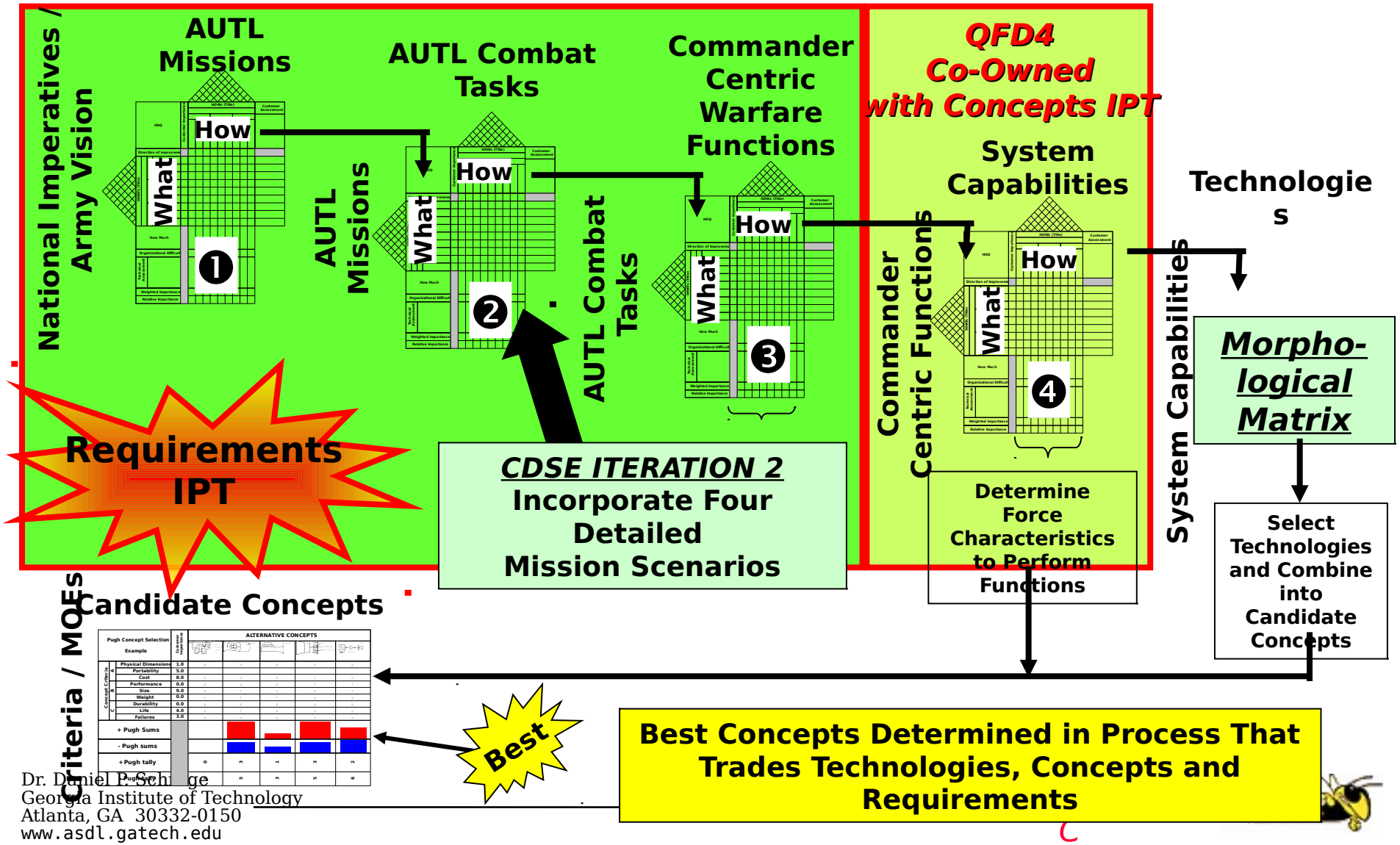
Focus on Requirements Flowdown through QFD



Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
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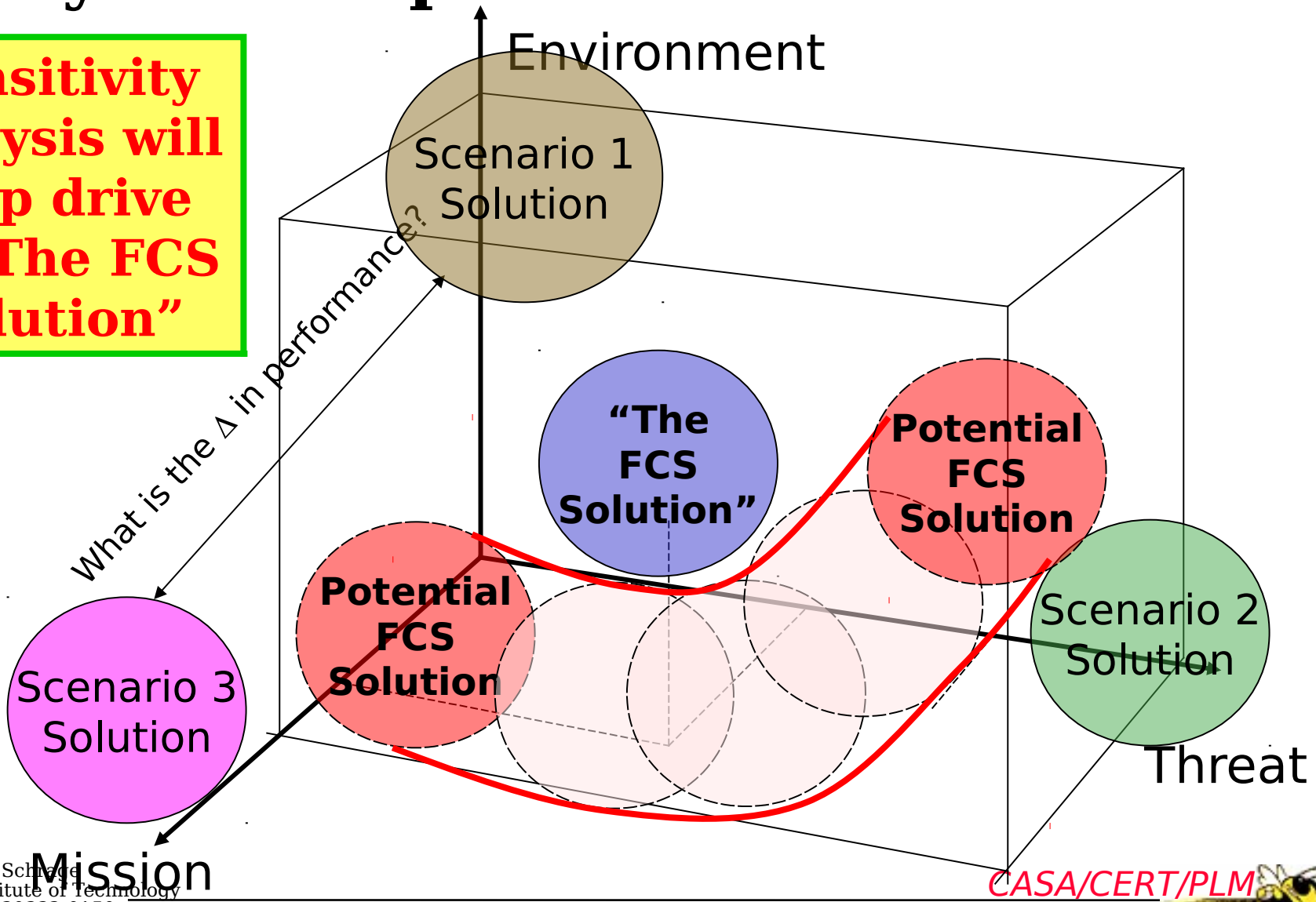
Representative FCS Trade Studies

- **Communications Trades**
  - Peer-to-Peer and Client-Server
  - Islands and Backbones
  - Frequency Bands and Bandwidth
  - QoS (Latency, Availability, Bandwidth)
- **C2 Trades**
  - Legacy, New, Organic, Joint
  - Initiative and Control
- **Platform Trades**
  - Tracks and Wheels
  - Weight Studies (16t, 9t, 6t)
  - Modularity and Commonality Studies
  - Hybrid and Conventional Propulsion
  - Turbine and Diesel
  - Wheel and Body Motors
  - Active and Passive Suspension
- **Force Trades**
  - UAVs and UGVs
  - Manned and Unmanned
  - Mounted snd Dismounted
  - BLOS / NLOS / LOS Mix
  - BU Size and Composition
- **Weapons Trades**
  - Guns and Missiles
  - 105 and 120 BLOS/LOS
  - Precision and Area Fires
- **Sensor Trades**
  - Radar, EO/IR, and Ladar
  - Systems (UAV, UGV, Mast, Tethered)
  - On Board and Off Board Fusion
  - ATR and Clutter (False Alarms)
- **Survivability Trades**
  - Active and Passive
  - Collective and Individual
  - Links and Nodes
- **HMI Trades**
  - Autonomy, Responsibility, Workload
  - Commonality, Simplicity
  - Motion and Maneuver
- **Logistics**
  - OPTEMPO and Sustainment
  - Deployment (Weights, Times, Pulses)
  - Prognostics, Distribution, Log Support

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

The Trade Space is Defined by a Full Spectrum of Scenarios

Sensitivity analysis will help drive to "The FCS Solution"



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Georgia Institute of Technology
Atlanta, GA 30332-0150
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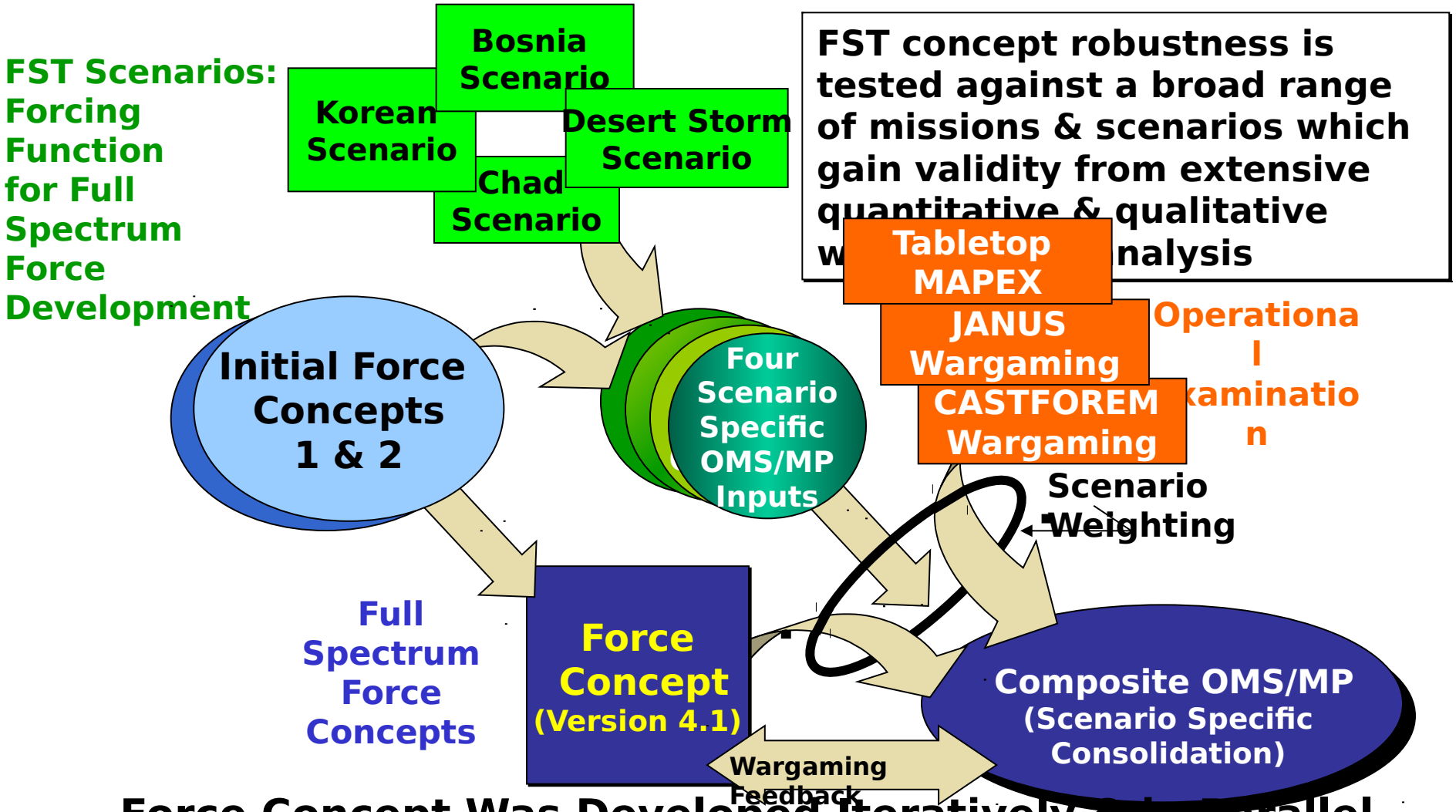
Scenario Driven OMS/MP Development


FST Scenarios: Forcing Function for Full Spectrum Force Development
Bosnia Scenario
Korean Scenario
Desert Storm Scenario
Chad Scenario
FST concept robustness is tested against a broad range of missions & scenarios which gain validity from extensive quantitative & qualitative w nalysis
Tabletop MAPEX
JANUS Wargaming
CASTFOREM Wargaming
Operationa l xaminatio n
Initial Force Concepts 1 & 2
Four Scenario Specific OMS/MP Inputs
Scenario Weighting
Full Spectrum Force Concepts
Force Concept (Version 4.1)
Composite OMS/MP (Scenario Specific Consolidation)
Wargaming Feedback

Force Concept Was Developed Iteratively & In Parallel With OMS/MP Refinements

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Evolution of FCS Force Concepts

Concept 1

- Heavy reliance on robotic ground vehicles
  - More RSTA and assault
- Deployable by current rotary wing aircraft
  - Max vehicle weight 10 tons
- Client-server information architecture
- Evolutionary comms and software systems

Concept 2

- Heavy reliance on NLOS range engmts / UAVs
- Significantly more payload volume
  - Mostly 18-ton vehicles
- Peer-to-peer information architecture

2012 FUE

Baseline

- Blending of Concept 1 and 2--Robotics and NLOS engmts
- 6-ton ARVs, 9-ton CVs, 16-ton max vehicle weight
- Helo vertical envelopment with smaller vehicles
- 16 ton limit for C-130 deployment on unimproved runways
- Hybrid information architecture
  - Peer-to-Peer with communication islands
- Based on Small Unit Operations comms technology
- New software services

2012 FUE

BLK I / BLK II

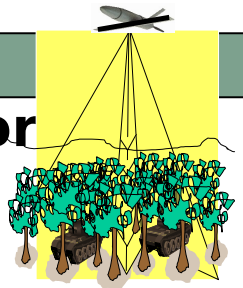
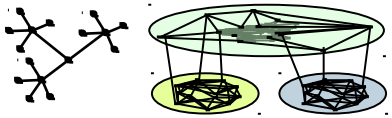
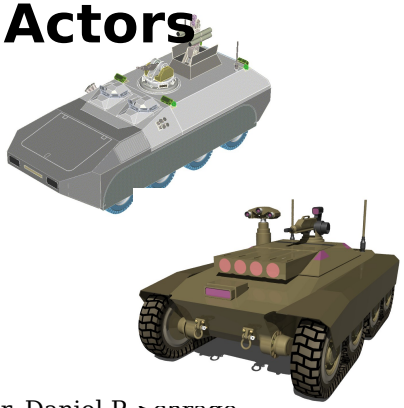
- BLK I – Employ available weapons systems
  - Most vehicles manned
  - 9-ton vehicles become 16 ton
- BLK II – Employ advanced weapons systems
  - Many advanced robotic systems
- Same information and comms arch. as Baseline

2008 FUE BLK I

2013 FUE BLK II

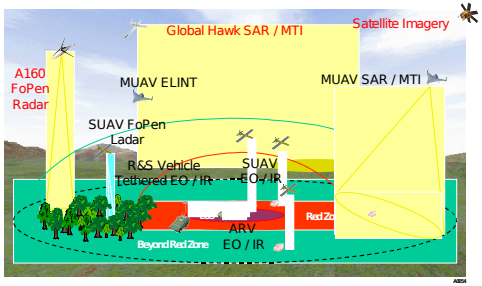
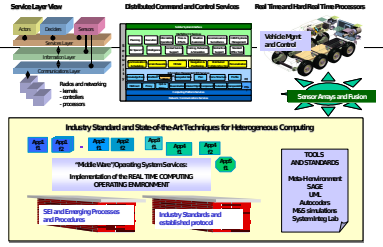
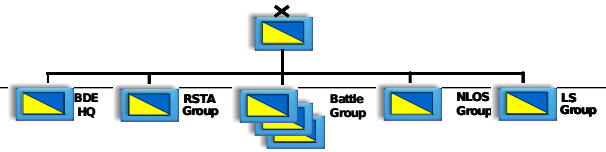
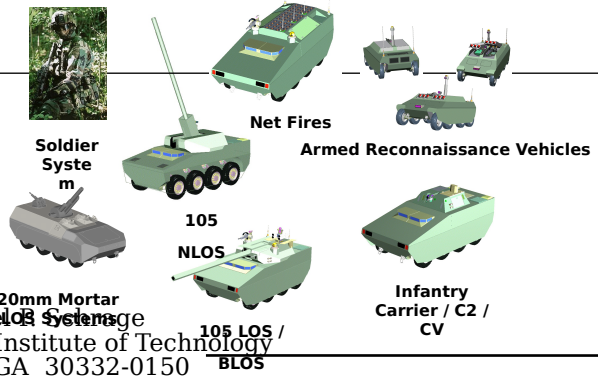
Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Concept Baseline Alternatives Summary

	Concept 1	Concept 2
Sensor 	• Smaller Number of UAVs • Large Number of Modestly Capable Ground Sensors (ARVs)	• Larger Number of UAVs • Small Number of Highly Capable Ground Sensors (RSTA Vehicle)
Information 	• Client Server • Evolutionary Software	• Peer-to-Peer • Distributed, Dynamic
Deciders	• Highly Automated Commander-Centric (Unit/Group)	• Highly Automated Commander-Centric (Group/Brigade)
Actors 	• Full Spectrum, but Weighted for the Red Zone • Robotic ARV, DF, Netfires, NLOS • Manned C2, CV, and Infantry Carrier • CH-47 Transportable (<10 tons) • Many Dispersed 4, 6, and 9 Ton Vehicles (~650)	• Full Spectrum, but Weighted for Beyond the Red Zone • Robotic Netfires, Small UGV • Manned C2, Infantry Carrier, Direct Fire, RSTA and Short Range NLOS • C-130 Transportable (<18 tons) • Common Chassis with Modules (~340)

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Baseline 2012 Concept
Network Centric Functional Overview

 **Sensors**	**Soldier** **Organic UAVs, UGVs (EO/IR, FoPen, SAR, MTI)** **Organic Manned R&S with Tethered Sensors** **Aided Target Recognition** **Augmenting UAVs and Satellites**
 **Info System**	**Organic Multi-Layer Peer-to-Peer Coms** **Opportunistic Ground, UAV, and Satellite Links** **Integrated Software/Hardware Open Architecture** **Distributed Warfighter Services**
 **Deciders**	**Brigade, Battle Group, Battle Unit** **Common Relevant Operating Picture** **Decision and Planning Aids**
 **Actors**	**Precision and Area NLOS Fires** **Precision BLOS / LOS Weapons** **OCSW on all Combat Vehicles** **Mix of Manned and Unmanned Platforms** **Infantry / Soldier Systems** **Large Number of Stowed Kills**

Dr. Daniel A. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

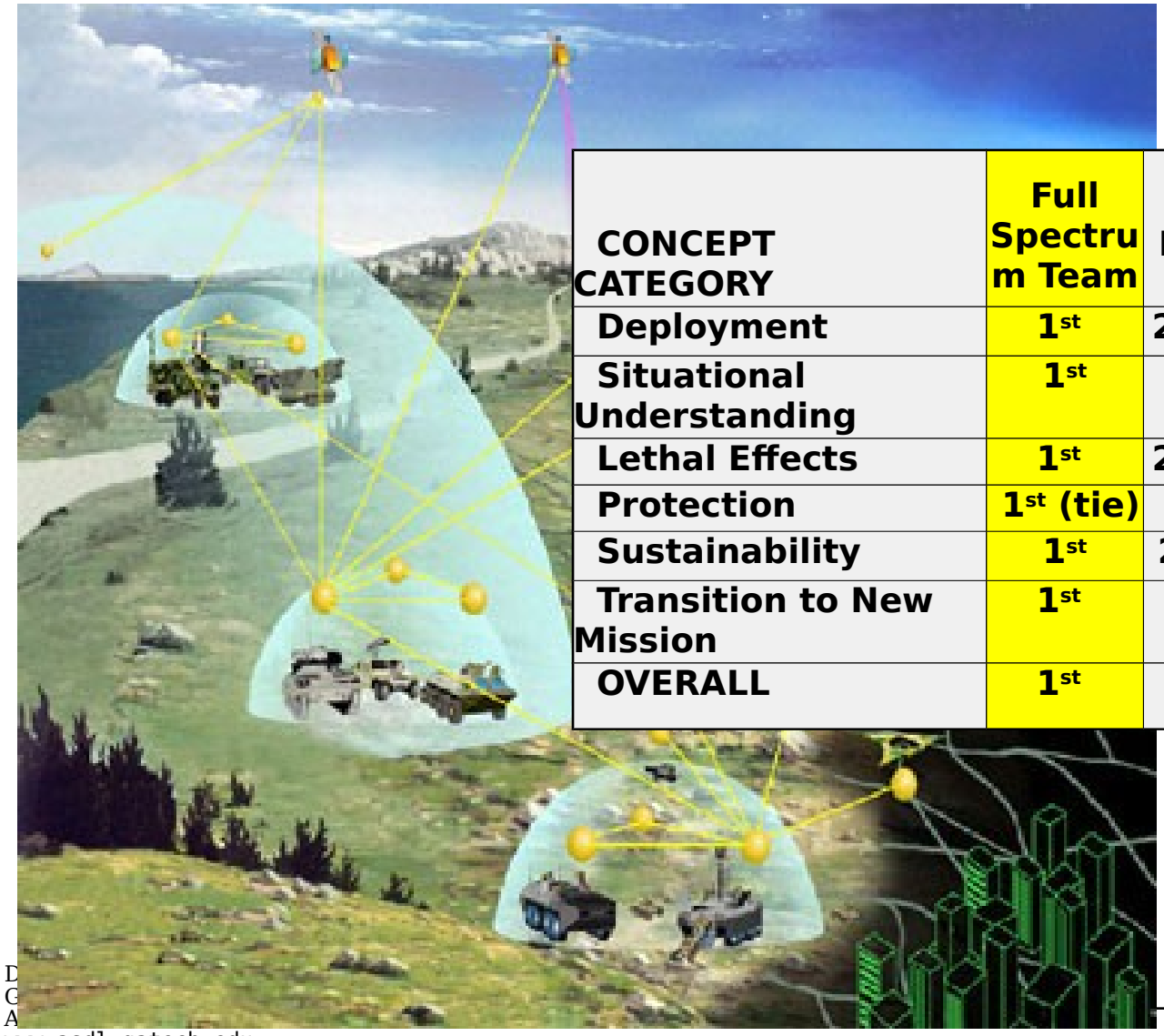
FCS Phase I Results

- Talented team pulled together through a generic IPPD methodology extended to address the 'system of systems' problem for FCS CDSE
- An integrated set of simple tools proved useful for the first iteration through the process
- Success of the Concept Development and Systems Engineering (CDSE) Process developed and utilized is summarized by the rankings by the government's independent assessment team
- Elements of the process are being continued by the Boeing-SAIC Lead System Integrator (LSI) through the current FCS Phase

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

(FCS)

Government Independent Assessment Team's Phase 1 competitive scores (awarded Nov 2001)



CONCEPT CATEGORY	Full Spectrum Team	Boeing	Gladiator (Lockheed/ TRW)	FocusVision (GDLS/ Raytheon)
Deployment	1st	2nd (tie)	2nd (tie)	2nd (tie)
Situational Understanding	1st	4th	3rd (tie)	3rd (tie)
Lethal Effects	1st	2nd (tie)	2nd (tie)	2nd (tie)
Protection	1st (tie)	4th	1st (tie)	2nd
Sustainability	1st	2nd (tie)	2nd (tie)	4th
Transition to New Mission	1st	4th	2nd	3rd
OVERALL	1st	4th	2nd	3rd

F/A-18 Example

Example Application

- Link the appropriate aircraft sizing/synthesis and economic tools plus probabilistic methods to create testbed environment; model the F/A-18C (using substantiation data for validation)

- With F/A-18E/F requirements (Ref. AIAA Paper 98-4701) as drivers, look at relation of technology metrics on requirements mathematically

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Expanding Missions: The F/A-18E/F

Maritime Air Superiority	Air Combat Fighter	Fighter Escort	Recce	Close Air Support	Air Defense Suppression	Day/ Night Attack	All Weather Attack
F-14D NATF			F/A-18 A/B/C/D			A-6F	
F/A-18 E/F							

Ref. Young, et.al. AIAA-98-4701, 1998.

How can such multi-role vehicles be examined as potential solutions for the war-fighter with respect to technologies, requirements, and design constraints ?

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Process

The traditional process of identification of an overall objective to be optimized is replaced by the following process:

1) Using Response Surface Method to mathematically represent combined requirements-technology-configuration space

2) search for alternatives (configuration changes plus technology infusion) that satisfy *requirements and constraints (TIES method)*

3) simultaneously, optimize on desirements within this feasible space (continuous) or set (discrete) then, perform sensitivity studies to show the perturbation of the solution due to *possible* changes in requirements and design variables.

Thus, the customer/decision maker has information with regards to the choice between tolerating a *relaxation in requirements* or *accepting achievable performance* levels

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
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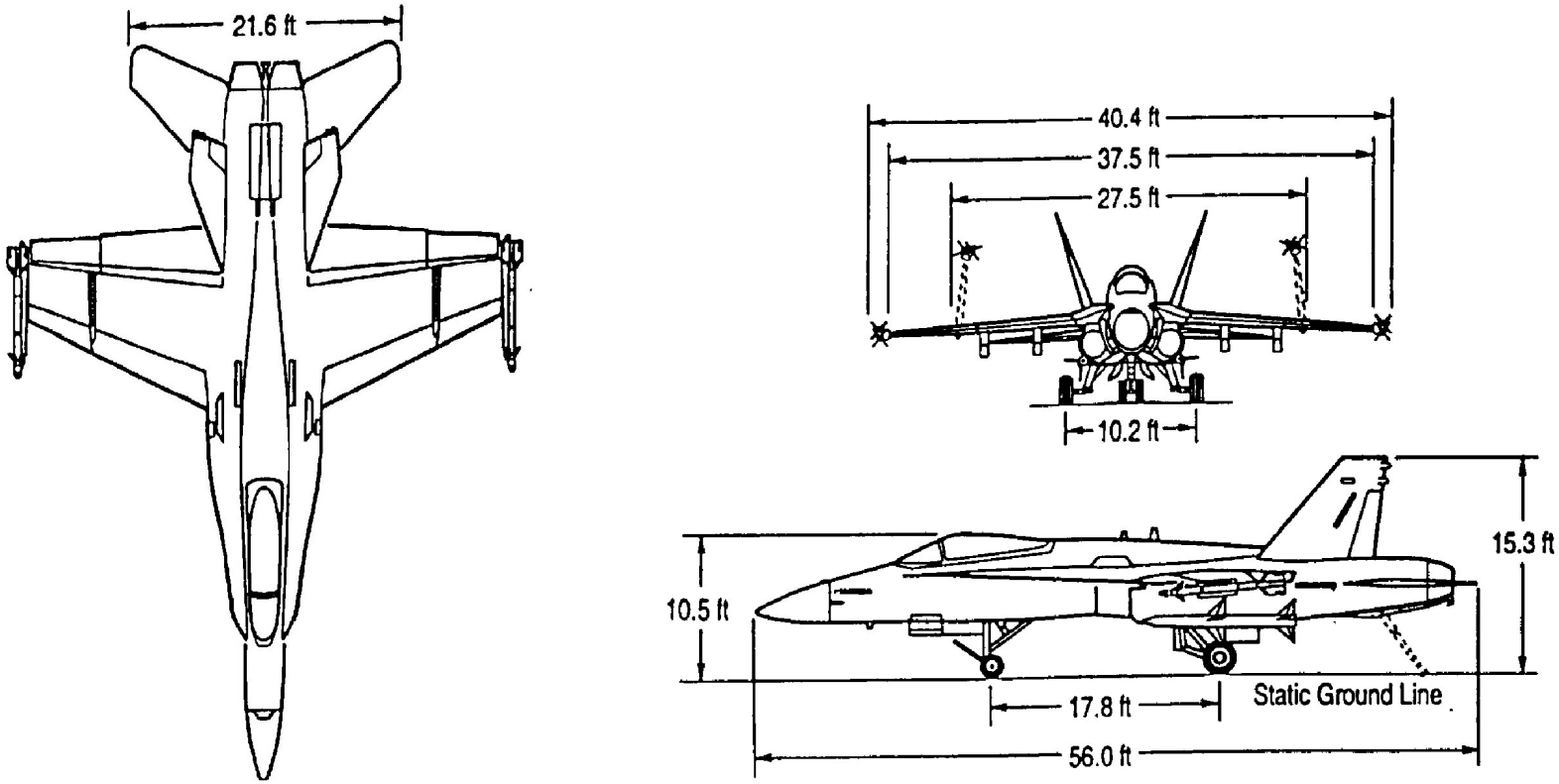
F/A-18C Basic Geometry



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Georgia Institute of Technology
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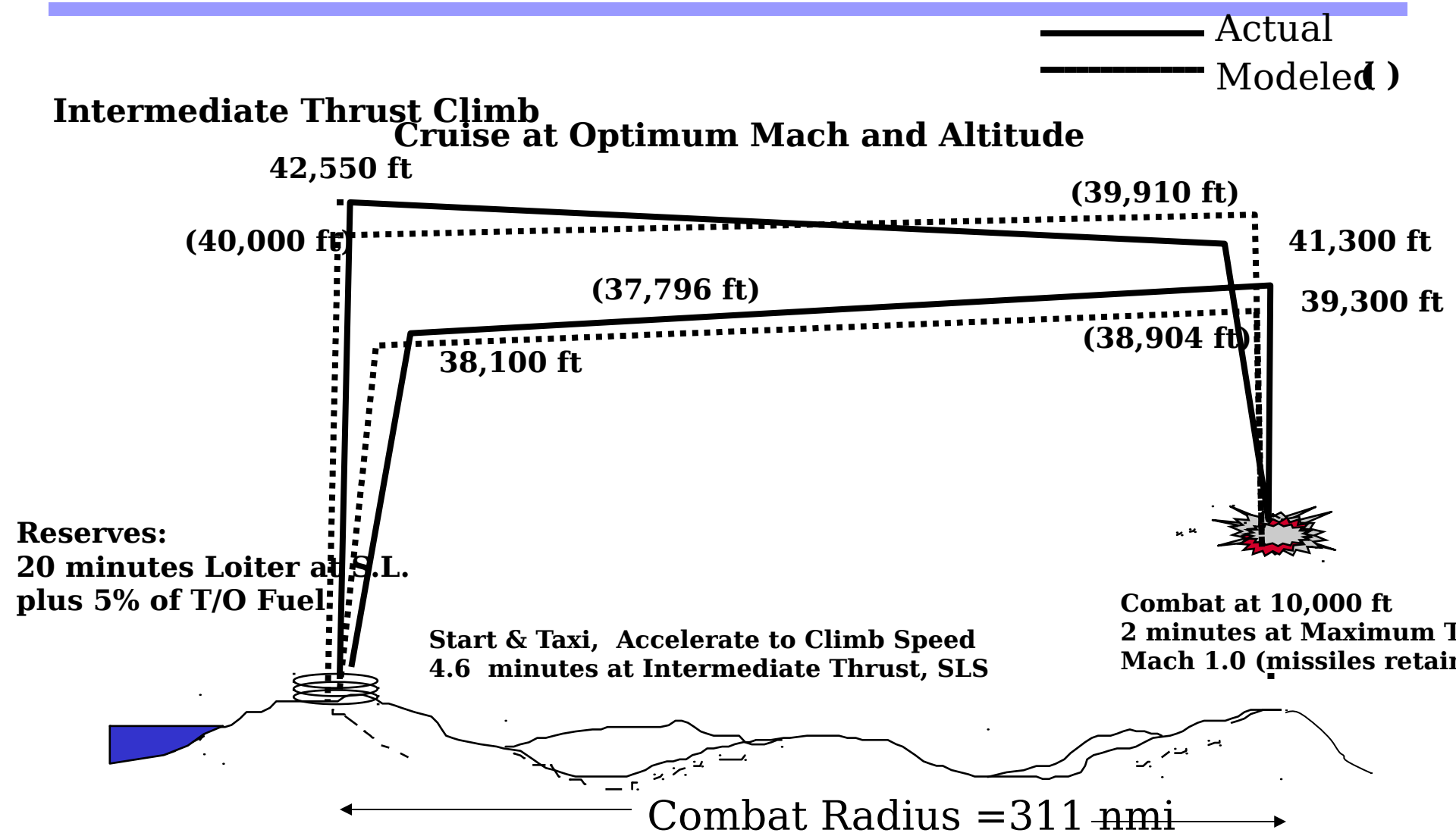
Primary Mission- Fighter Escort



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Georgia Institute of Technology
Atlanta, GA 30332-0150
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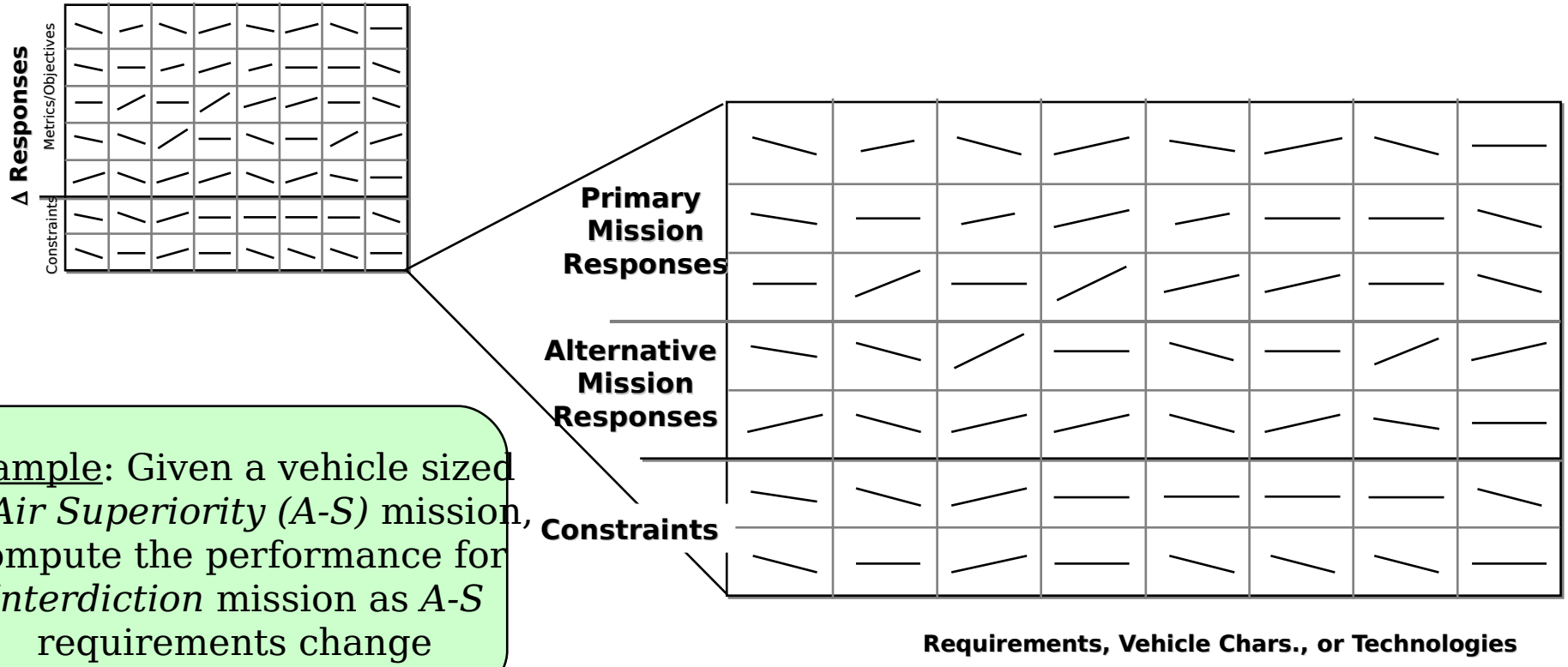
Alternate Missions- Addressing Multi-role Capability

- Requirements can include performance against a wide variety of missions
- Vehicle sizing proceeds based on a primary mission and then fallout performance of the sized vehicle on alternate missions is computed and tracked



Example: Given a vehicle sized for *Air Superiority (A-S)* mission, compute the performance for *Interdiction* mission as *A-S* requirements change

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
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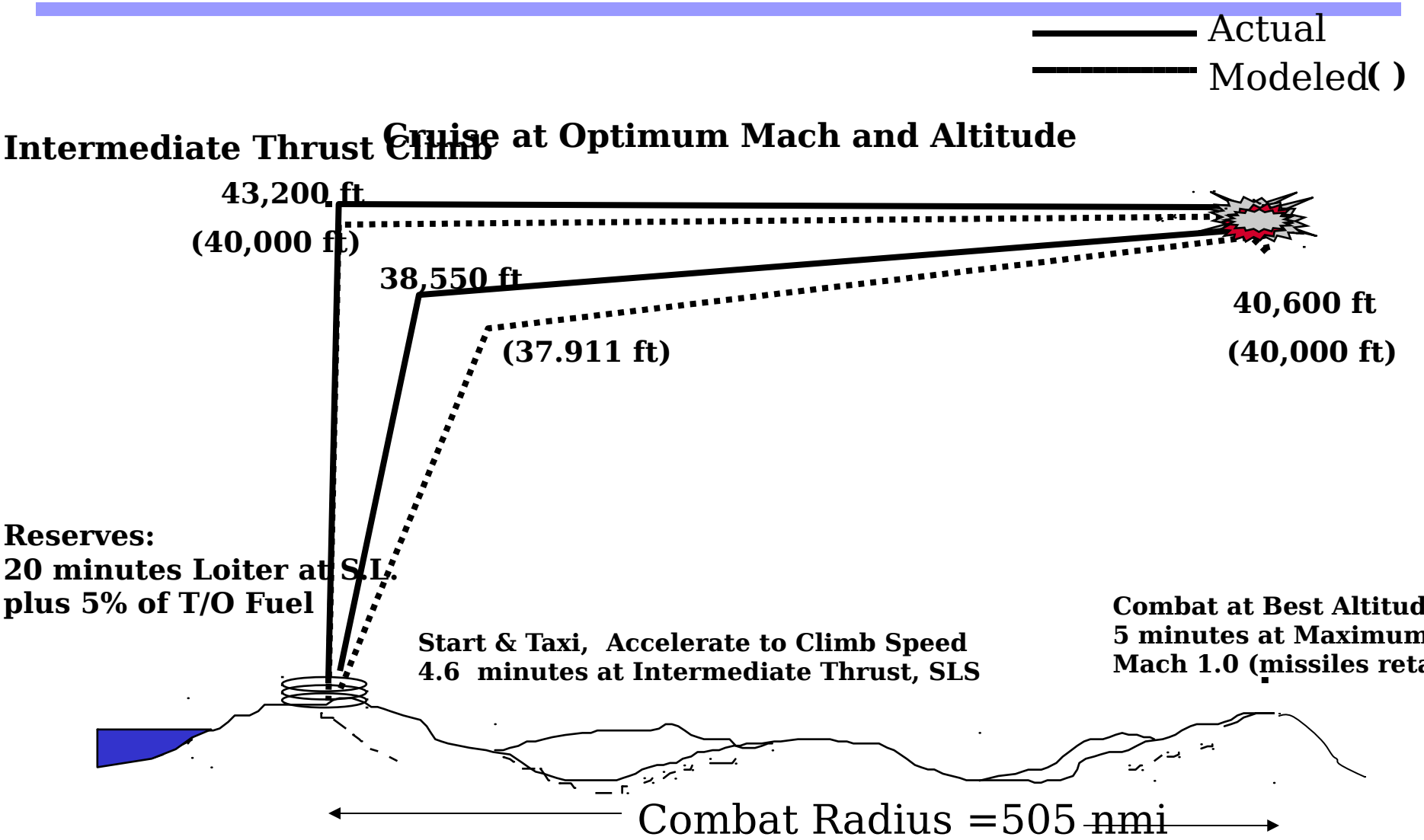
Alternate Mission: Hi Hi Hi



Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
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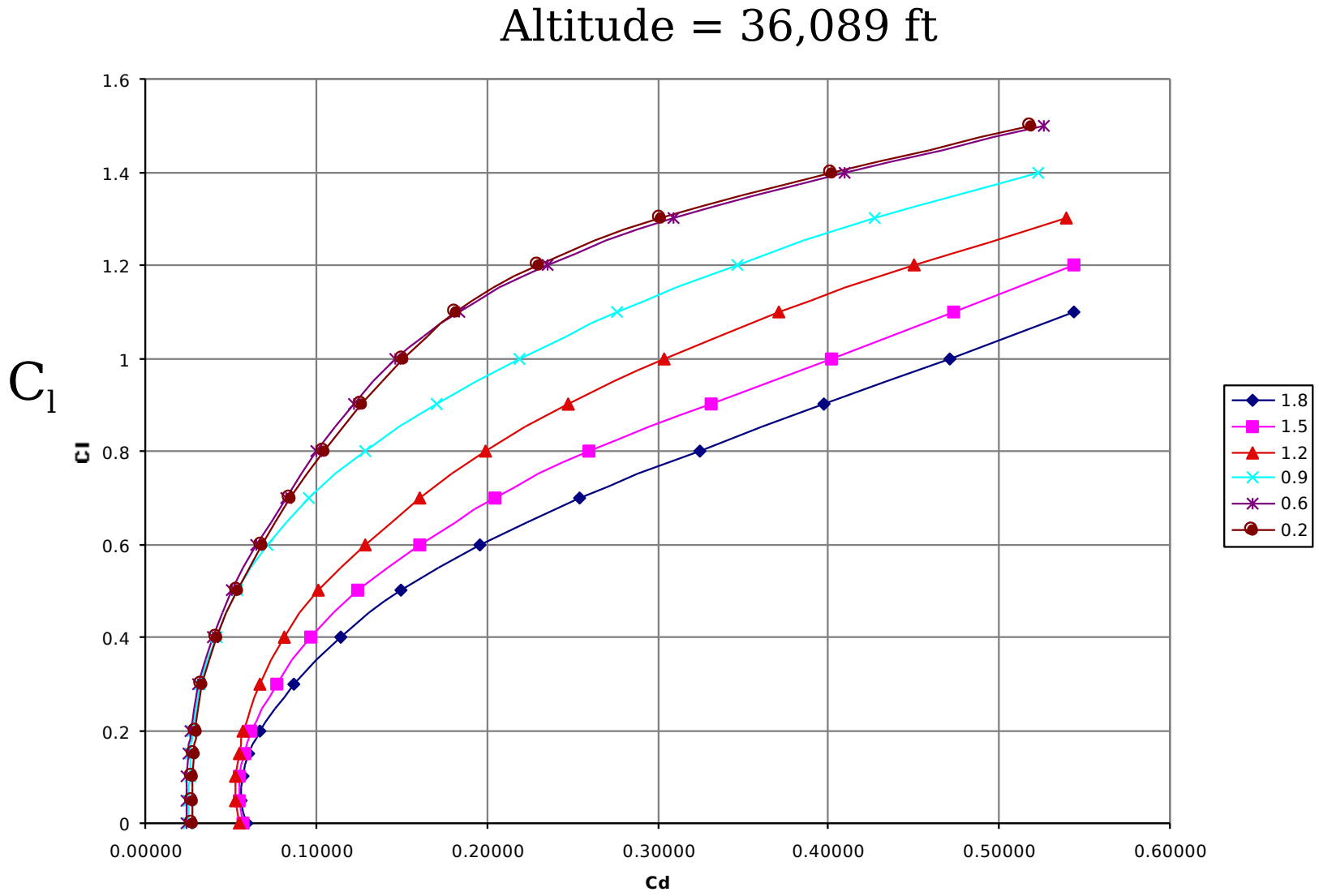
Correlation of Drag Polars for Varying Mach Numbers



Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
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Propulsion Modeling

F404-GE-402 Augmented Turbofan Engine

- The F404-GE-402 is an increased performance derivative of the F404 and is used in the F/A-18C
- Features a dual-spool mixed flow turbofan architecture, 3X7X1X1 turbomachinery configuration
- F404 Engine performance deck based on installed engine data for the F/A-18C
- Engine performance data source: "*F/A-18C Substantiating Performance Data with F404-GE-402 Engines*" Report MDC91B0290

General Specifications:

- Thrust: 17,700 lb
- SFC (max A/B): 1.74 lbm/lbf-hr
- SFC (IRP): 0.81 lbm/lbf-hr
- Airflow (SLS): 146 pps
- Weight: 2,282 lb
- Length: 159 in
- Dia

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
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Weight Breakdown-Validation

- Sizing/Synthesis Code Used: FLight OPtimization System (FLOPS)
- F/A-18C Baseline Modeled in FLOPS calibrated against actual substantiation data from manufacturer
- Highly accurate model (errors in weights less than 1%)

F/A18C Weight Breakdown Comparison		
Group	F/A18C	Baseline Model
Wing	3,919	3,918
Tail Group	1,005	1,006
Body	5,009	5,009
Alighting Gear	2,229	2,228
Propulsion Group		
Engines	4,420	4,417
Engine Section Gear Box Controls Starting System	921	922
Fuel System	1,078	1,078
Flight Controls	1,061	1,062
Auxiliary Power Plant	206	206
Instruments	84	84
Hydraulics	351	352
Electrical	592	592
Avionics	1,864	1,864
Armament, Gun, Launchers, Ejectors	948	948
Furnishings, Load/Handling, Contingency	631	631
Air Conditioning	641	642
Crew	180	180
Unusable Fuel	207	207
Engine Fluids	114	115
Chaff, Ammunition	252	252
Miscellaneous	58	58
Operating Weight Empty	**25,770**	**25,771**
Missiles		1,410
(2) AIM-7F	1,020	
(2) AIM-9L	390	
Mission Fuel	10,860	10,857
Takeoff Gross Weight	**38,040**	**38,038**

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
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Economic Assumptions

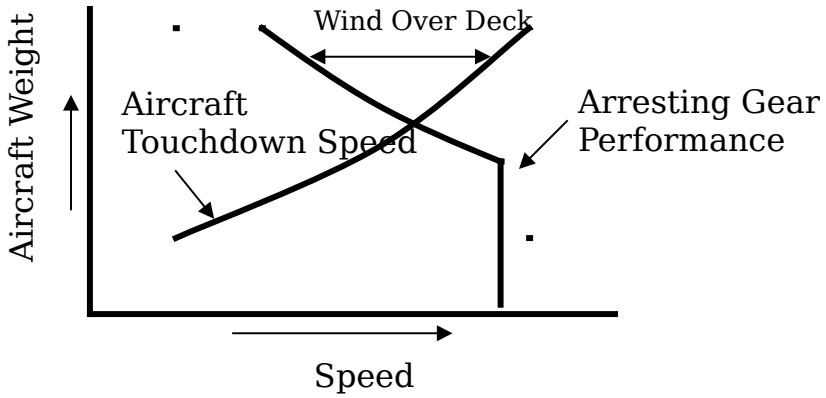
- MALCCA (Military Aircraft Life Cycle Cost Analysis) in-house code used to determine notional aircraft economics

- Baseline File created starting with defaults based on the mili aircraft assumptions (primarily sourced from F-15 and F-16 d

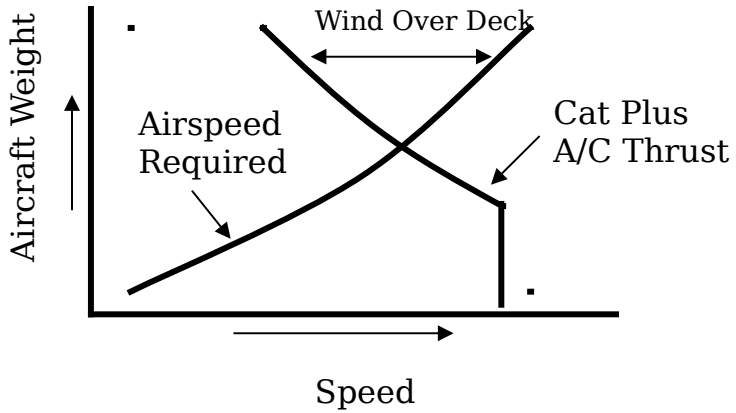
Inflation Factor	3.3%
Dollar Year	1994
Year of Program Initiation	2000
Final Year of Production	2023
#Operational Vehicles	2530 units
System Economic Life	20 years

Wind Over Deck

Recovery Wind Over Deck



Launch Wind Over Deck

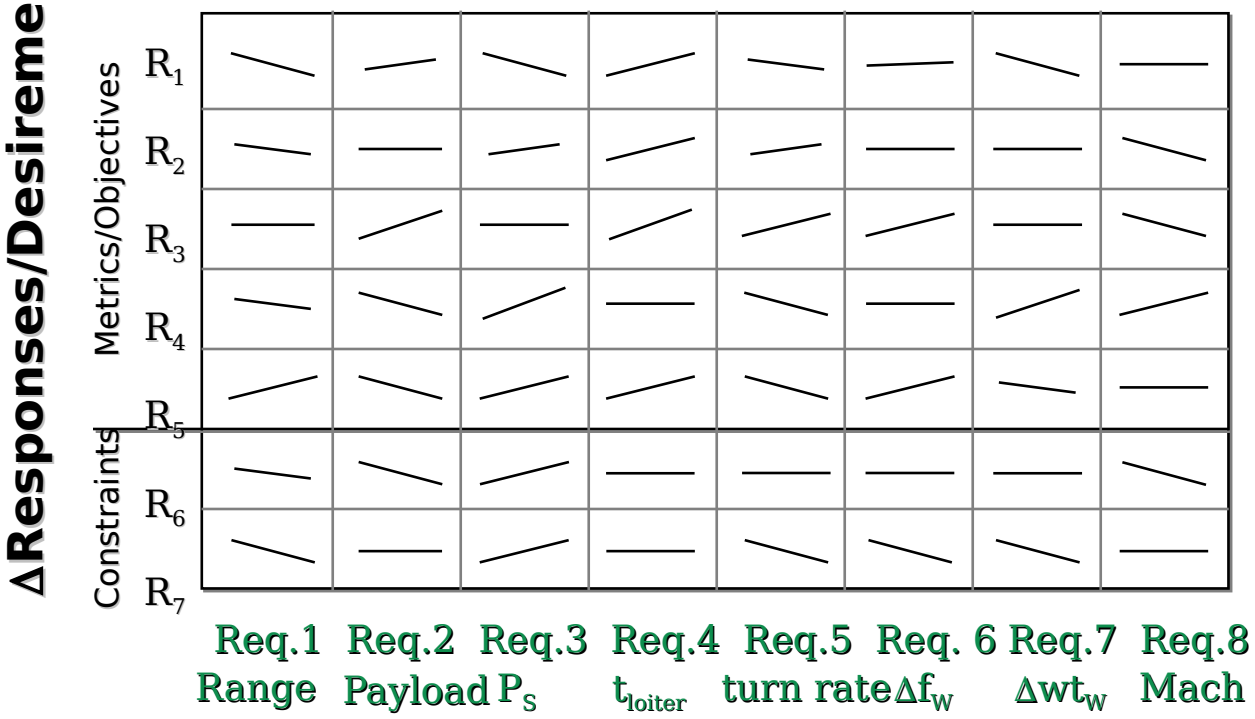


- Aircraft Touchdown Speed = 1.05 * Vapp
- Airspeed Required = Calculated Liftoff Speed
- Arresting Gear Performance Calculated at Limit Cap

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Responses and Top Level Requirements

Snapshot 1



Example Responses:

Gross Weight
Probability of Survival
Lethality
O+S
Acquisition Cost

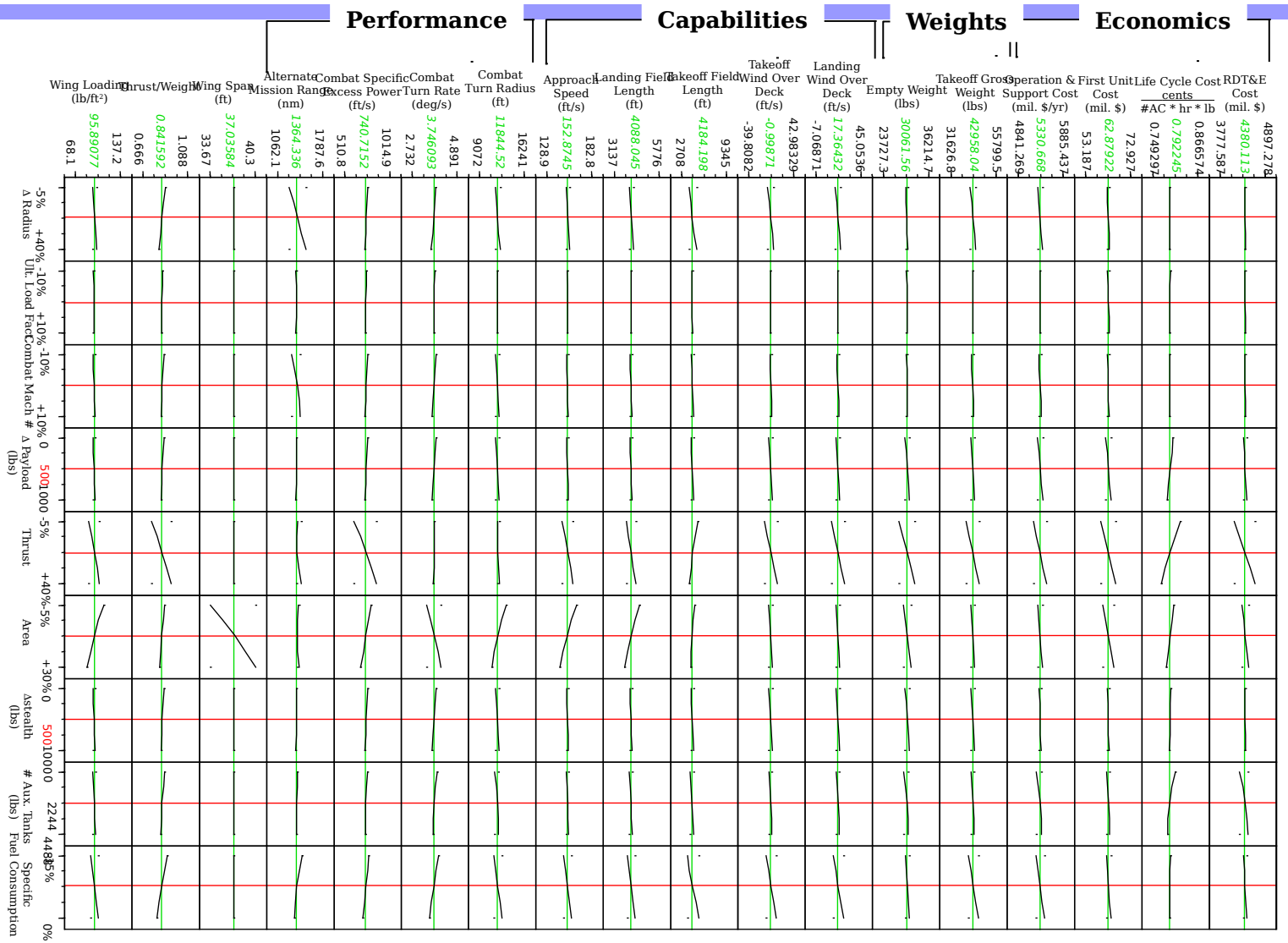
Approach Speed (constraint)
TOFL (constraint)

T/W and W/S may belong in either the requirements or the responses section - depending on how the programs are set up

This approach de-emphasizes the geometry of an aircraft, and instead focuses on the mission requirements. However, it does require a baseline aircraft configuration. **Geometry and Technologies are fixed,** while Requirements vary. Each vector of top level requirements maps to a specific mission.

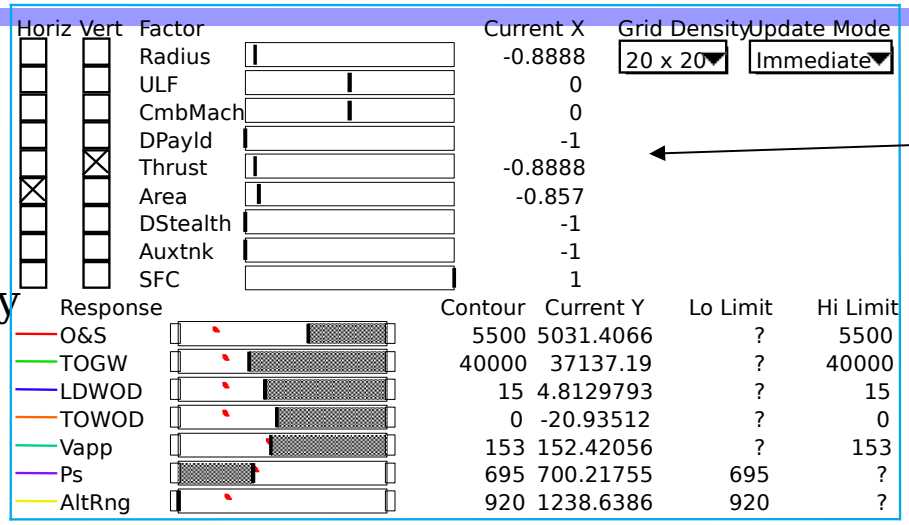
Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Requirement RSEs for Notional F/A-18C



Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Requirements Exploration: F/A-18C Design Contours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CmbMach 0
DPayld -1
Thrust -0.8888
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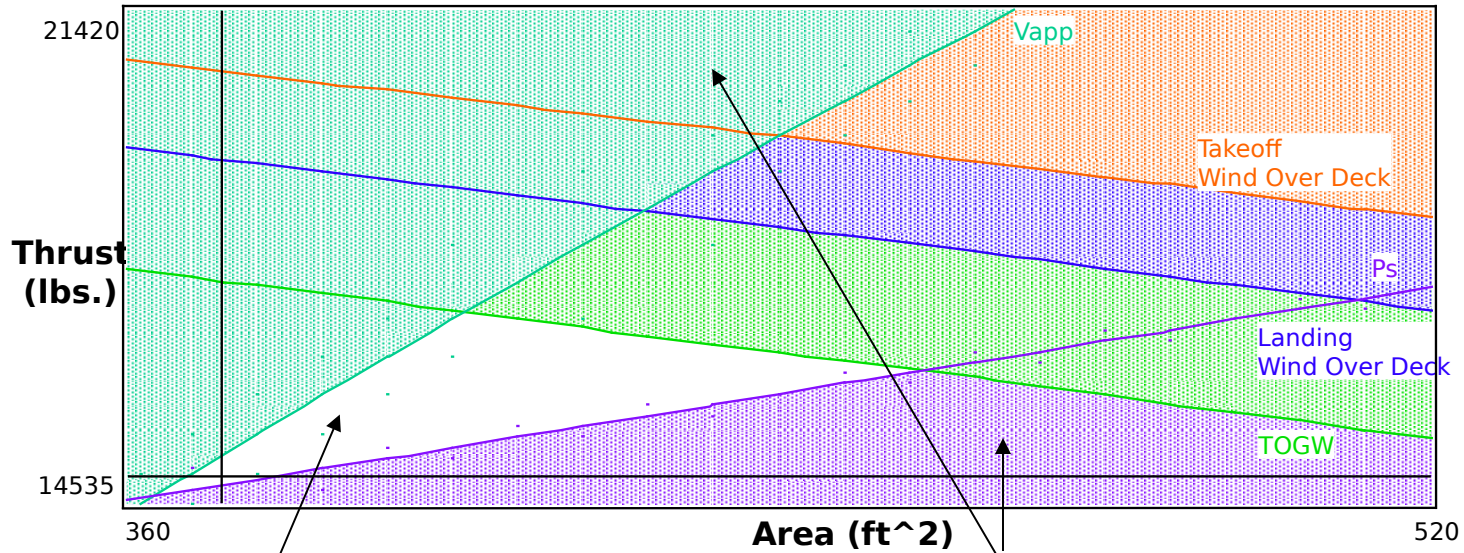
DStealth -1
Auxtnk -1
SFC 1
Response Contour Current Y Lo Limit Hi Limit
O&S 5500 5031.4066 ? 5500
TOGW 40000 37137.19 ? 40000
LDWOD 15 4.8129793 ? 15
TOWOD 0 -20.93512 ? 0
Vapp 153 152.42056 ? 153
Ps 695 700.21755 695 ?
AltRng 920 1238.6386 920 ?

Slide bars control variable va

Response contours may be set here

Constraints are set her

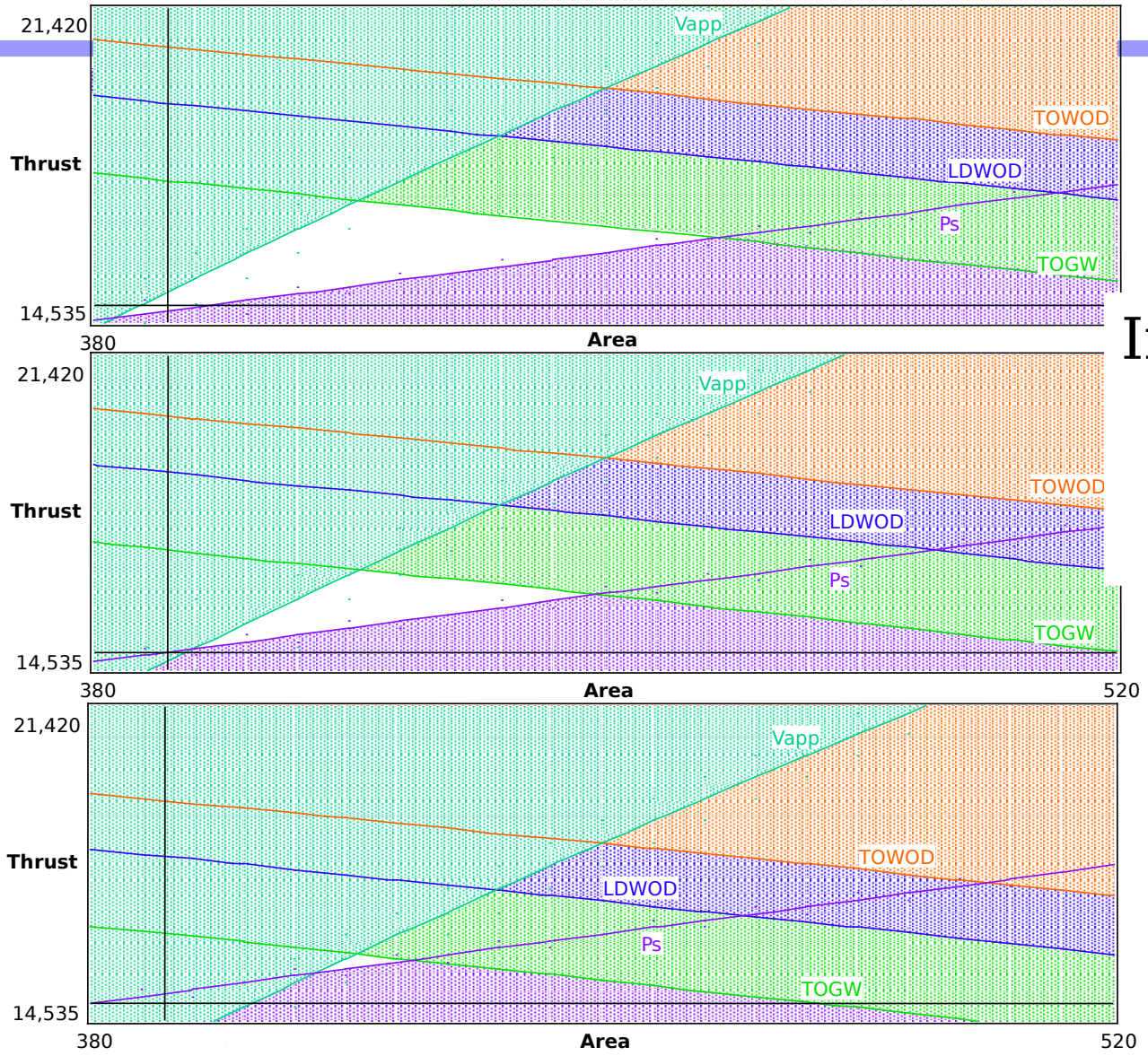


White area indicates available design space, while filled areas indicate areas which violate set constraints

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Effects of Increase in *Combat Radius Req.*

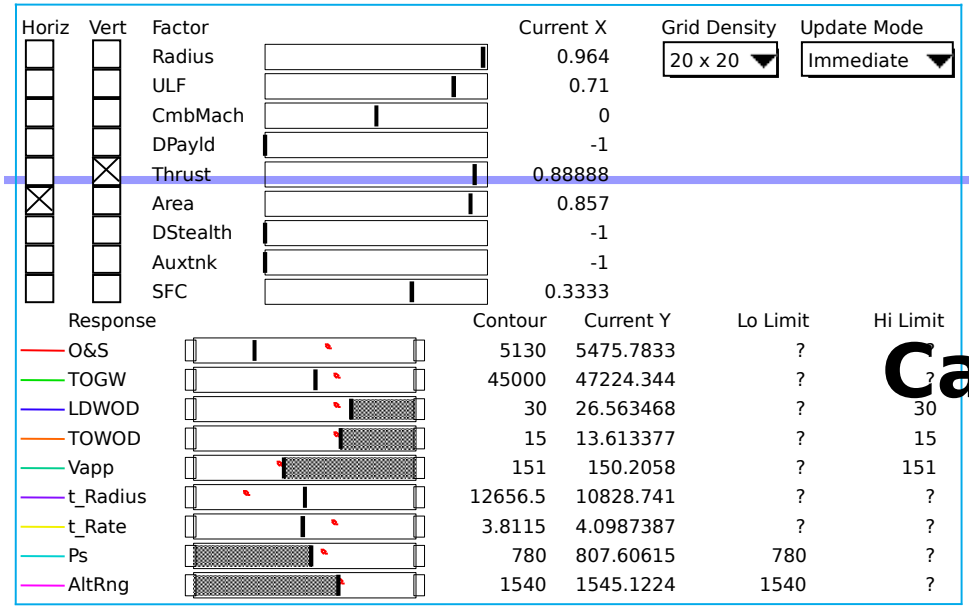
Decreasing Feasible Space

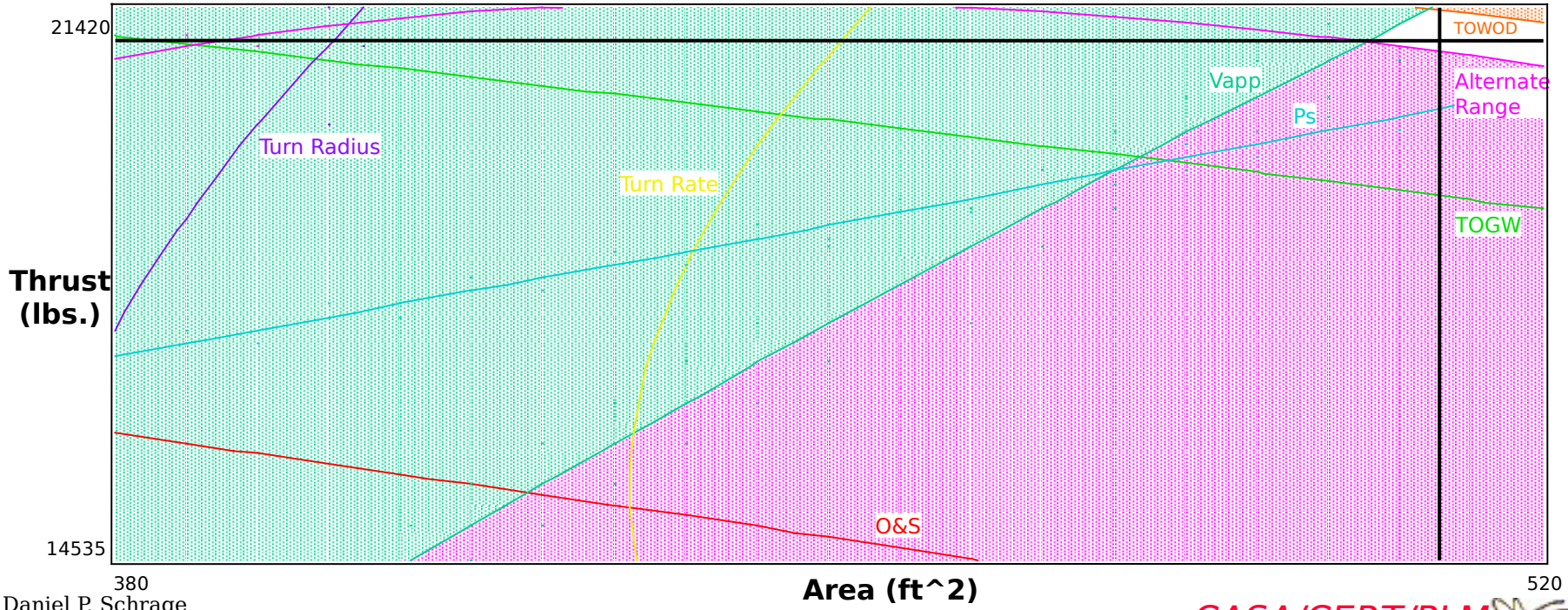


Increasing Combat Radius Reqmt.

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Exploring the Space: Capturing the F/A-18E/F

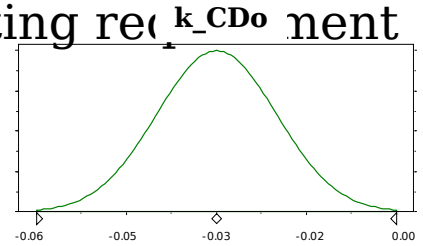


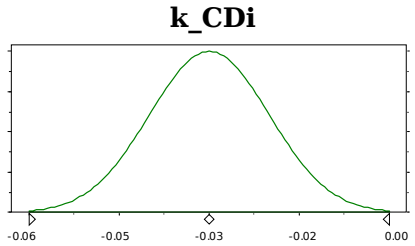


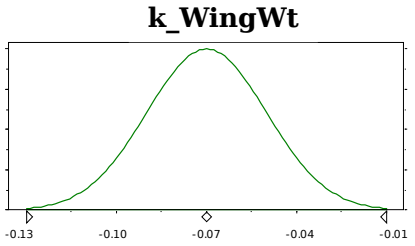
Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

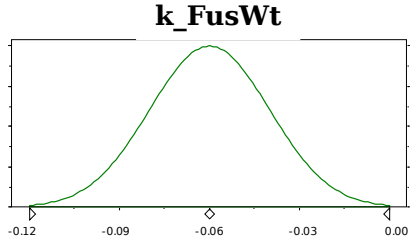
RDS Example: TOGW Req. for Notional F/A-18 (1)

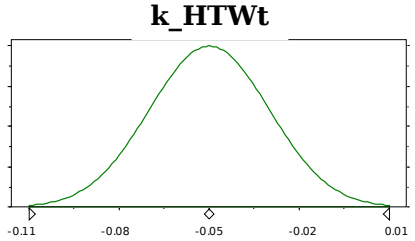
Scenario 1: Conservative tech. improvements gives low confidence of meeting re[illegible]ment

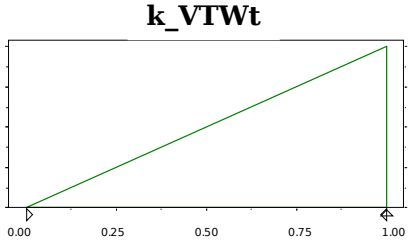


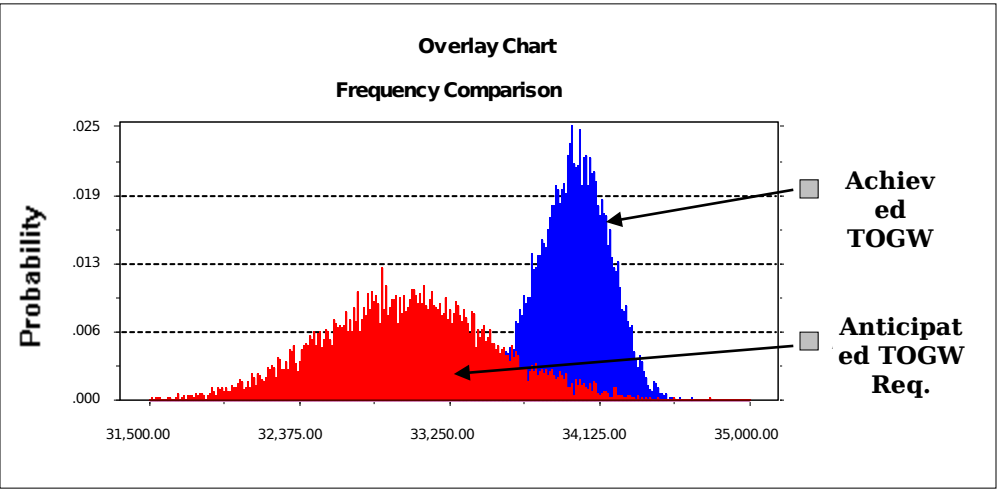


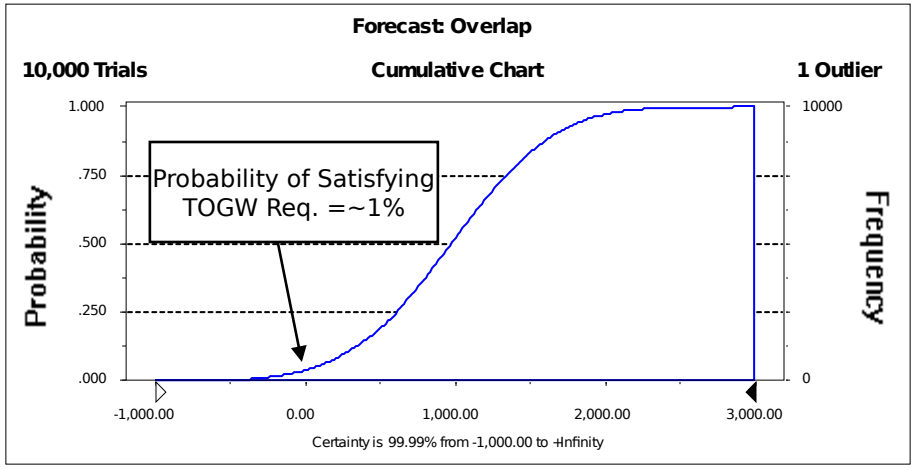








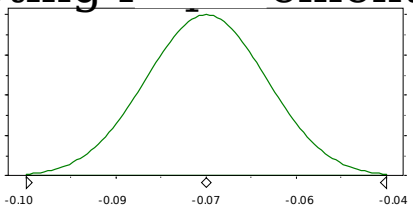


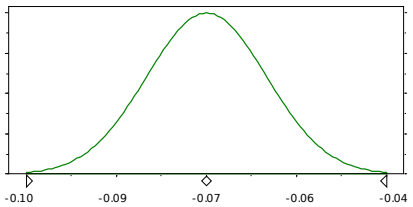


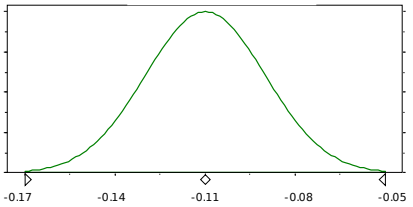
Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

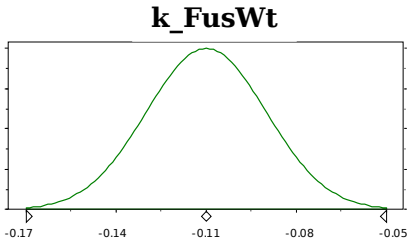
RDS Example: TOGW Req. for Notional F/A-18 (2)

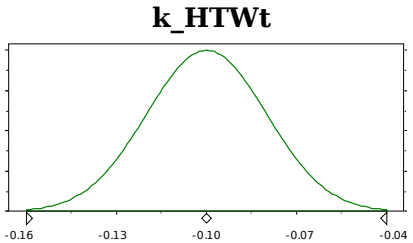
Scenario 2: Aggressive tech. improvements gives higher confidence of meeting r k_CDo ement

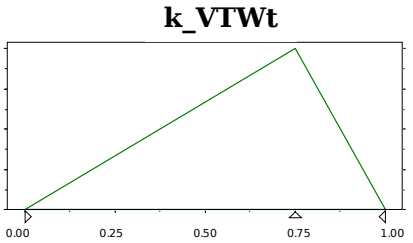


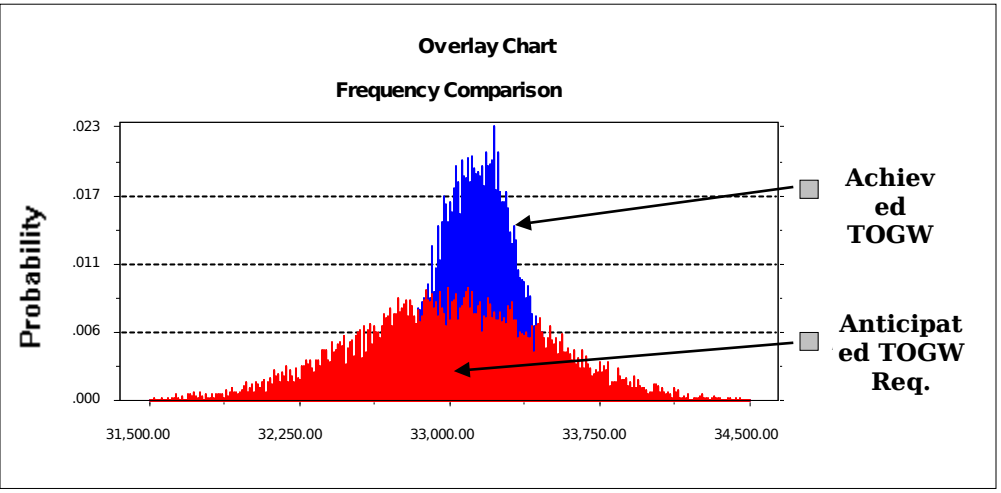


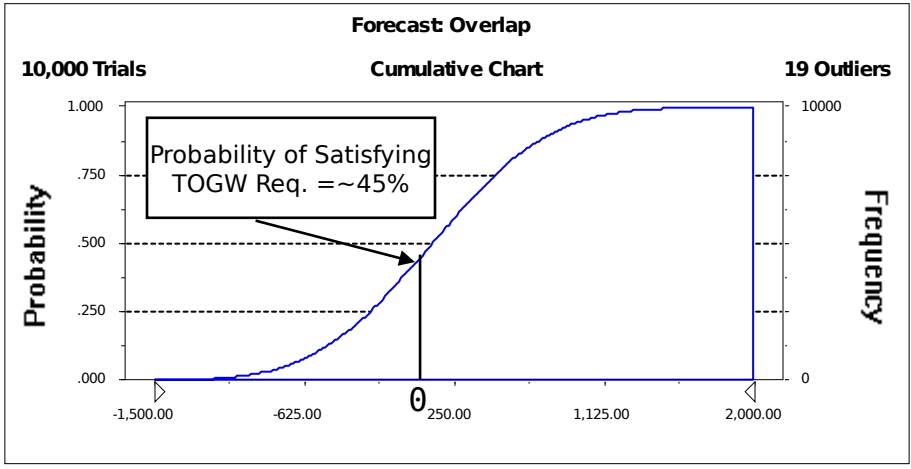








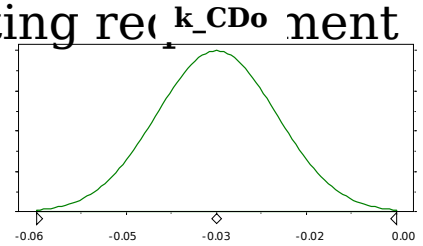


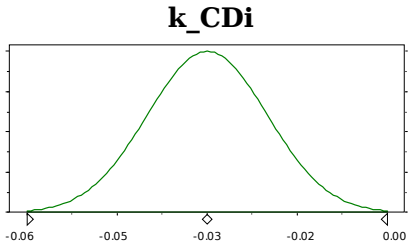


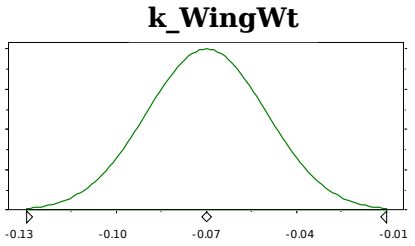
Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

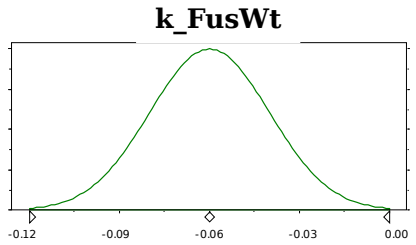
RDS Example:O&S $ as an Anticipated Requirement (1)

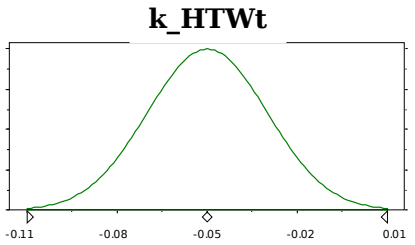
Scenario 1: Conservative tech. improvements gives low confidence of meeting re[illegible]nent

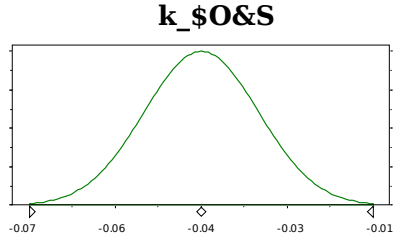


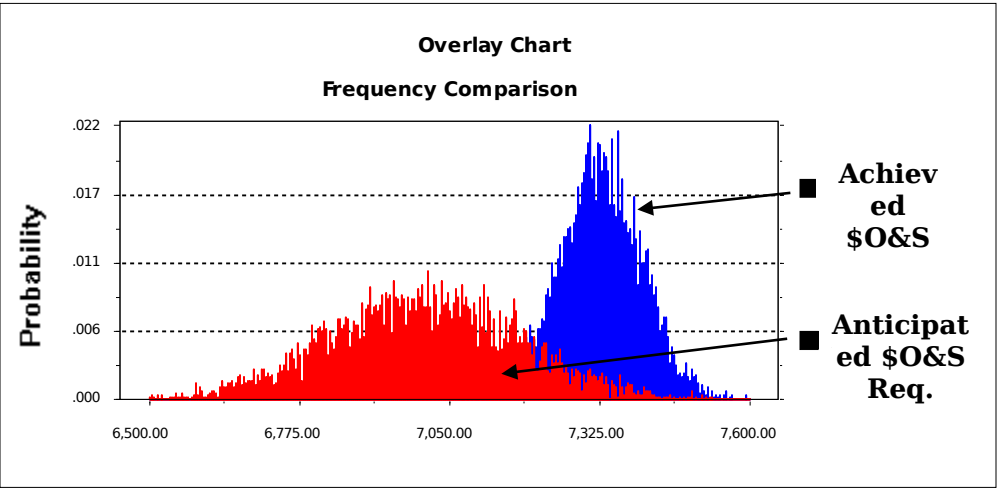


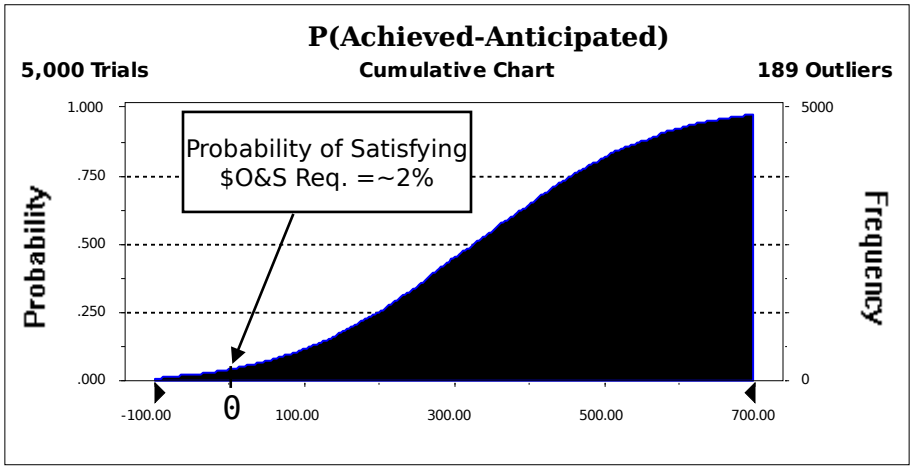








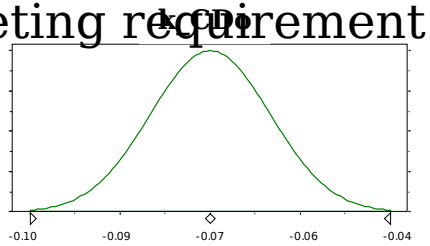


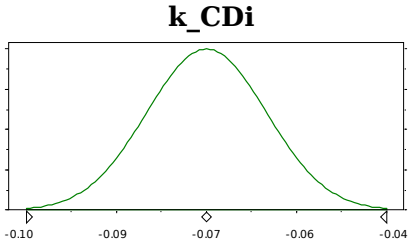


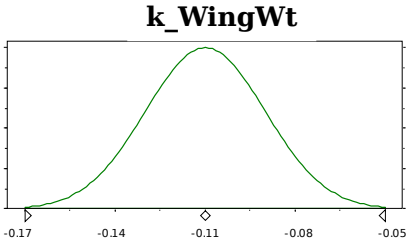
Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

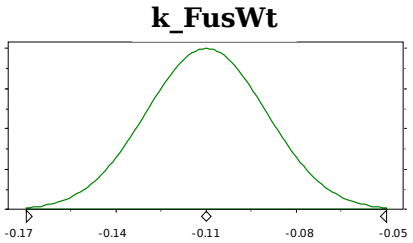
Example: $O&S as an Anticipated Requirement (2)

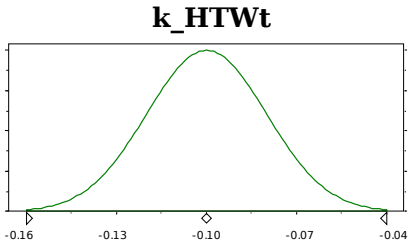
Scenario 2: Aggressive tech. improvements gives higher confidence of meeting requirement

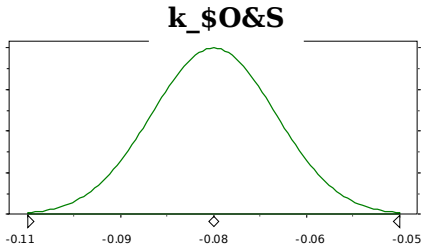


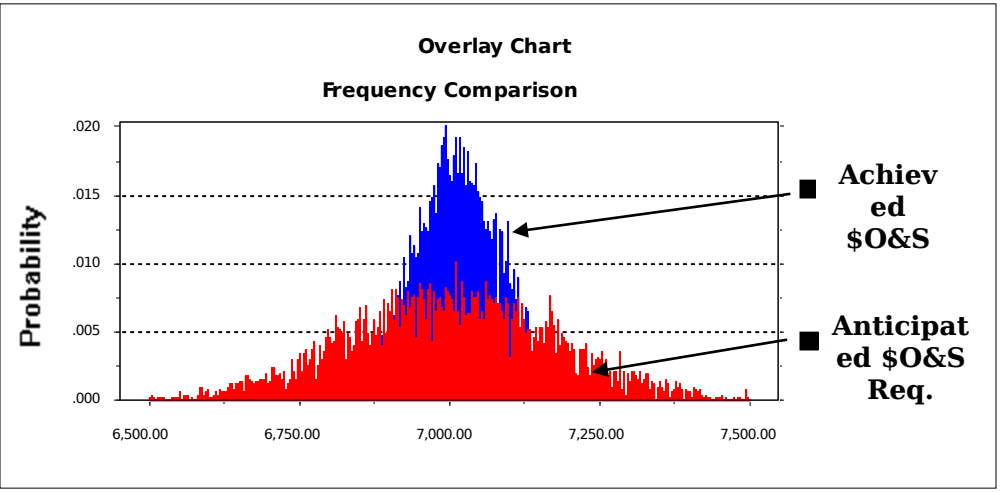


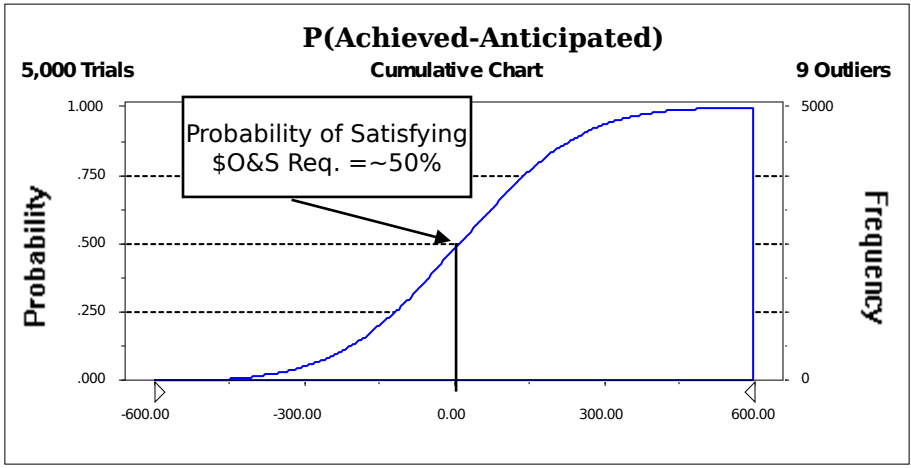












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Georgia Institute of Technology
Atlanta, GA 30332-0150
www.asdl.gatech.edu

Summary and Conclusions

- Systems Engineering has its *roots in Aerospace*
- Modern Systems Engineering must reflect the *Quality Revolution*
- The *Five Lean Principles* should serve as *guiding principles* for a Modern Systems Engineering Approach
- Integrated Product and Process Development (IPPD) required in the *Fuzzy Front End to Establish Value* for subsequent principle implementation: *Value Stream*, *Process Flow*, *Customer Pull*, and *Perfection*
- Georgia Tech has developed an *IPPD through Robust Design Simulation (RDS) environment* that allows a Probabilistic Approach for the Fuzzy Front End
- The transition of the IPPD through RDS to a *Virtual Stochastic Life Cycle Design Environment* is necessary for full implementation of the *Five Lean Guiding Principles*

Dr. Daniel P. Schrage
Georgia Institute of Technology
Atlanta, GA 30332-0150
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